DOCUMENT RESUME

ED 124 384	88	SE 019 607

TITLE "Let There Be Light" Minicourse, Career Oriented Pre-Technical Physics.

INSTITUTION Dallas Independent School District, Tex.

SPONS AGENCY Bureau of Elementary and Secondary Education (DHEW/OE), Washington, D.C.

PUB DATE 74

NOTE 134p.; Photographs and shaded drawings may not reproduce well; For related documents, see SE 018 322-333 and SE 019 605-616

EDRS PRICE MF-$0.83 HC-$7.35 Plus Postage.

DESCRIPTORS Instructional Materials; Light; *Optics; Physics; *Program Guides; *Science Activities; Science Careers; Science Education; *Science Materials; Secondary Education; *Secondary School Science; Technical Education

IDENTIFIERS Elementary Secondary Education Act Title III; ESEA Title III

ABSTRACT

This instructional guide, intended for student use, develops the concept of light through a series of sequential activities. A technical development of the subject is pursued with examples stressing practical aspects of the concepts. Included in the minicourse are: (1) the rationale, (2) terminal behavioral objectives, (3) enabling behavioral objectives, (4) activities, (5) resource packages, and (6) evaluation materials. Along with a definition of light, the concepts of reflection and refraction and such topics as fiber light and the photoelectric effect are developed. This unit is one of twelve intended for use in the second year of a two-year vocationally oriented physics program. (CP)

CAREER ORIENTED PRE-TECHNICAL PHYSICS

"Let There Be Light"

Minicourse

ESEA Title III Project

1974

dallas independent school district

BOARD OF EDUCATION

Eugene S. Smith, Jr., *President*

Bill C. Hunter, *Vice-President*

Emmett J. Conrad, M.D.

James Jennings

Nancy Judy

Lawrence Herkimer

Kathlyn Gilliam

Sarah Haskins

Robert Medrano

ADMINISTRATIVE OFFICERS

Nolan Estes
General Superintendent

H. S. Griffin
Deputy Superintendent

Rogers L. Barton
Associate Superintendent — Development

Frances Allen
Assistant Superintendent
Adaptive Education

Larry Ascough
Assistant Superintendent — Communications

Otto M. Fridia, Jr.
Assistant Superintendent
Elementary Operations

Ruben Gallegos
Assistant Superintendent
Program Development

Carlton C. Moffett
Assistant to the General Superintendent

Ben Niedecken
Attorney

H. D. Pearson
Assistant Superintendent
Business

Joe M. Pitts
Assistant Superintendent
Personnel Development

George Reid
Assistant Superintendent
Secondary Operations

John J. Santillo
Assistant Superintendent
Personnel

B. J. Stamps
Assistant Superintendent
Instructional Services

Weldon Wells
Assistant Superintendent
Support Services

dallas independent school district

October 8, 1974

Nolan Estes
General Superintendent

This Minicourse is a result of hard work, dedication, and a comprehensive program of testing and improvement by members of the staff, college professors, teachers, and others.

The Minicourse contains classroom activities designed for use in the regular teaching program in the Dallas Independent School District. Through minicourse activities, students work independently with close teacher supervision and aid. This work is a fine example of the excellent efforts for which the Dallas Independent School District is known. May I commend all of those who had a part in designing, testing, and improving this Minicourse.

I commend it to your use.

Sincerely yours,

Nolan Estes

General Superintendent

NE:mag

CAREER ORIENTED PRE-TECHNICAL PHYSICS

"LET THERE BE LIGHT"

MINICOURSE

<u>RATIONALE (What this minicourse is about)</u>

This minicourse will introduce you to some of the technical aspects of light. Light is so much a part of our environment that many people never consciously try to understand its nature, nor do they learn to appreciate the vital roles it plays. Two vital roles which light plays in our lives are concerned with vision and with photosynthesis (the process whereby green plants use light energy to manufacture plant products).

However, language pays tribute to light--we say, "We're in the <u>dark</u>, when we don't know something; and we use the expression, "throwing some light on the subject," when we have overcome a problem. When things are not going well, we say we are in a "dark" mood. We also speak of "black" magic (evil), or a "bright day" (when things are going well); and who has not heard about (or viewed) the "soap opera" called <u>The Guiding Light</u>?

Keep a folder or notebook containing a neat account of your investigations, observations, and other written work required for this minicourse; this account will be used as one basis for evaluation of your work.

In addition to the Rationale, this minicourse contains the following sections:

1) TERMINAL BEHAVIORAL OBJECTIVES (Specific things you are expected to learn from the minicourse)

2) ENABLING BEHAVIORAL OBJECTIVES (Learning "steps" which will enable you to eventually reach the terminal behavioral objectives)

3) ACTIVITIES (Specific <u>things</u> <u>to</u> <u>do</u> to help you learn)

4) RESOURCE PACKAGES (Instructions for carrying out the learning <u>Activities</u>, such as procedures, references, laboratory materials, etc.

5) EVALUATION (Tests to help you learn and to determine whether or not you satisfactorily reach the terminal behavioral objectives):

   a) Self-test(s) with answers, to help you learn more.

   b) Final test, to help measure your overall achievement.

<u>TERMINAL BEHAVIORAL OBJECTIVES</u>:

When you have completed this minicourse, you will demonstrate an understanding of some of the basic technical ideas of light by being able to:

1) trace man's attempts to determine the properties and speed of light and to write a simple description of light.

2) explain, in terms of a simple model, the release of photoelectrons from light-sensitive metal surfaces and to discuss some of the general behavior of photoelectrons.

3) show familiarity with the laws of reflection of light by a plane mirror and the images formed by a plane mirror and to construct ray diagrams for the formation of simple images in a plane mirror.

4) show familiarity with the properties of light striking a curved mirror and the images formed by the curved mirror, to construct ray diagrams for the formation of simple images by a curved mirror, and to use mirror formulas for determining the location and size of images.

5) show familiarity with the basic concepts of the refraction of light and to utilize and apply the laws of refraction to simple cases.

6) solve simple problems in photometry.

7) identify some optical principles used in fiber optics.

8) describe a simple model of polarized light and list some technical applications of such light.

9) describe a simple model of the phenomena of interference and diffraction of light.

ENABLING BEHAVIORAL OBJECTIVE #1:	ACTIVITY 1-1	RESOURCE PACKAGE 1-1
Roughly describe attempts to determine the properties and speed of light, and write an acceptable description of light.	Read and complete Resource Packages 1-1, 1-2, and 1-3.	"What Is Light?" RESOURCE PACKAGE 1-2 "Speed of Light" RESOURCE PACKAGE 1-3 "Description of Light"
ENABLING BEHAVIORAL OBJECTIVE #2:	**ACTIVITY 2-1**	**RESOURCE PACKAGE 2-1.1**
Understand the laws of reflection of light by a plane mirror, understand the images formed by a plane mirror, and construct ray diagrams for the formation of images on a plane mirror.	Read and complete Resource Packages 2-1.1 through 2-1.7.	"Reflection I" RESOURCE PACKAGE 2-1.2 "Reflection II" RESOURCE PACKAGE 2-1.3 "Reflection III"

ENABLING BEHAVIORAL OBJECTIVE #2:

(For a statement of this objective, please see page 3 of this minicourse.)

RESOURCE PACKAGE 2-1.4

"Reflection IV"

RESOURCE PACKAGE 2-1.5

"Mirror, Mirror on the Wall"

RESOURCE PACKAGE 2-1.6

"Image Problem"

RESOURCE PACKAGE 2-1.7

"Some Applications"

ACTIVITY 2-2

Complete Resource Package 2-2.1 and check your answers using Resource Package 2-2.2.

RESOURCE PACKAGE 2-2.1

"Reflection Exercise"

RESOURCE PACKAGE 2-2.2

"Answers"

ENABLING BEHAVIORAL OBJECTIVE #3:

Describe the general properties of light striking a curved mirror; describe and illustrate the images formed by a curved mirror; use the mirror formula to determine the size and location of images.

ACTIVITY 3-1

Read and complete Resource Packages 3-1.1 through 3-1.6.

RESOURCE PACKAGE 3-1.2

"Curved Mirror Investigation"

RESOURCE PACKAGE 3-1.2

"Curved Mirrors"

RESOURCE PACKAGE 3-1.3

"Ray Construction"

8

ENABLING BEHAVIORAL OBJECTIVE #3:

(For a statement of this objective, please see page 4 of this minicourse.)

ACTIVITY 3-2

Complete Resource Package 3-2.1 and check your answers using Resource Package 3-2.2.

RESOURCE PACKAGE 3-1.4

"Customer Satisfaction"

RESOURCE PACKAGE 3-1.5

"Curved Mirror Usage"

RESOURCE PACKAGE 3-1.6

"The Old Light-Bulb-In-The-Empty-Socket Trick!

RESOURCE PACKAGE 3-2.1

"Curved Mirror Exercise"

RESOURCE PACKAGE 3-2.2

"Answers to Exercise"

ENABLING BEHAVIORAL OBJECTIVE #4:

Describe a simple model for the refraction of light; explain and apply the laws of refraction.

ACTIVITY 4-1

Read and complete Resource Packages 4-1.1 through 4-1.4.

RESOURCE PACKAGE 4-1.1

"Refraction I"

RESOURCE PACKAGE 4-1.2

"Refraction II"

RESOURCE PACKAGE 4-1.3

"Index of Refraction"

RESOURCE PACKAGE 4-1.4

"Atmospheric Refraction"

ENABLING BEHAVIORAL OBJECTIVE #5: Develop fundamental skills related to solving problems in photometry.	**ACTIVITY 5-1** Read and complete Resource Packages 5-1.1 and 5-1.2.	**RESOURCE PACKAGE 5-1.1** "Illumination" **RESOURCE PACKAGE 5-1.2** "Photometry"
ENABLING BEHAVIORAL OBJECTIVE #6: Identify some optical principles used in fiber optics.	**ACTIVITY 6-1** Read and complete Resource Packages 6.1.1 and 6-1.2.	**RESOURCE PACKAGE 6-1.1** "Refractive Fibers" **RESOURCE PACKAGE 6-1.2** "Fiber Light"
ENABLING BEHAVIORAL OBJECTIVE #7: Identify some principles and technical applications of polarized light.	**ACTIVITY 7-1** Read and complete Resource Packages 7-1.1 and 7-1.2.	**RESOURCE PACKAGE 7-1.1** "Polarized Light I" **RESOURCE PACKAGE 7-1.2** "Polarized Light II"
ENABLING BEHAVIORAL OBJECTIVE #8: Describe a simple model for the phenomena of interference and diffraction of light.	**ACTIVITY 8-1** Read and complete Resource Packages 8-1.1 and 8-1.2.	**RESOURCE PACKAGE 8-1.1** "Interference" **RESOURCE PACKAGE 8-1.2** "Diffraction"
	ACTIVITY 8-2 Complete Resource Package 9-2.1 and check your answers using Resource Package 9-2.2.	**RESOURCE PACKAGE 8-2.1** "Self-test"

Objective	Activity	Resource
ENABLING BEHAVIORAL OBJECTIVE #8: (For a statement of this objective, please see page 6 of this minicourse.)		RESOURCE PACKAGE 8-2.2 "Self-test Answers"
ENABLING BEHAVIORAL OBJECTIVE #9: Study the release of photoelectrons from light-sensitive metal surfaces.	ACTIVITY 9-1 Read and complete Resource Package 9-1.1.	RESOURCE PACKAGE 9-1.1 "Photoelectric Effect"
TERMINAL EVALUATION	ACTIVITY 10-1 When you feel ready, ask your instructor for the Final Evaluation. (Good luck!)	RESOURCE PACKAGE 10-1.1 "Final Evaluation"

RESOURCE PACKAGE 1-1

WHAT IS LIGHT?

Historical records tell us that people have long tried to determine the properties of light. For some, "Let there be light, and there was light," provided a sufficient explanation of light's origin; for others, this explanation was insufficient to satisfy their curiosity because it did not tell anything about light itself.

Listed below are a group of men who lived sometime during the period, fifth century B. C. to modern times, who played important roles in discovering properties of light. Write a brief description of each man's idea(s) regarding the properties of light and, where appropriate, tell how these properties related to the development of later ideas. Ask your instructor for suitable references should you not be sure where to find this information.

1. Empedocles (Greek philosopher) -
2. Aristotle (Greek philosopher) -
3. Rene' Descarte (French mathematician) -
4. Alhazen (Arabian physicist) -
5. Francisco Maria Grimaldi (Italian priest) -
6. Robert Hooke (English physicist) -
7. Christian Huygens (Dutch physicist) -

8. Isaac Newton (English physicist) -

9. Thomas Young (English physicist) -

10. James Clark Maxwell (English physicist) -

11. Augustin Fresnel (French physicist) -

12. Max Plank (German physicist) -

13. Albert Einstein (German physicist) -

RESOURCE PACKAGE 1-2

THE SPEED OF LIGHT

In endeavors to determine the properties of light, its speed has been of utmost importance. A widely held current belief is that the speed of light in free space (a vacuum) is the highest possible speed attainable in the universe. Because this speed (denoted by the symbol, c) is one of the most important physical constants, its precise determination is an important achievement of experimental science.

Listed below are a group of men who contributed to the determination of the speed of light. Write a short description of the process each man used in his investigation and draw a rough (but neat) sketch of the situation or apparatus used. Your instructor can give you appropriate references.

1. Galileo Galilei -
2. Olaus Roemer -
3. H. L. Fizeau -
4. Leon Foucault -
5. Albert Michelson -

Also, search literature for the latest value of the speed of light in free space, in m/sec and in mi/sec. Enter these values and their source in your notebook.

RESOURCE PACKAGE 1-3

DESCRIPTION OF LIGHT

Now that you have read about these scientists' search for a meaningful explanation of light and about their efforts to determine the speed of light, write your own description of light in your notebook. Ask your instructor to check your description.

RESOURCE PACKAGE 2-1.1

REFLECTION I

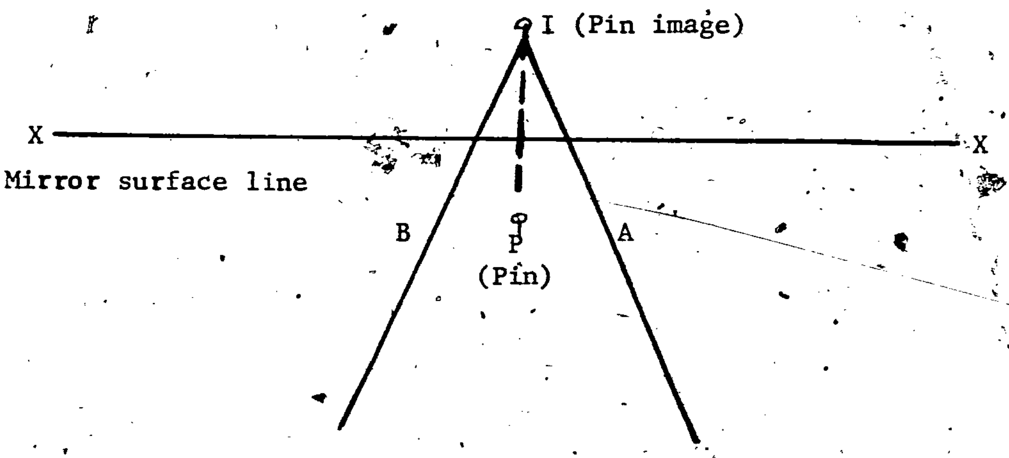
You will need the following:

- plane mirror
- wooden block
- wooden drawing board
- drawing compass
- protractor
- ruler
- rubber bands

Fig. 1
ANGLES OF INCIDENCE AND REFLECTION

Arrange the apparatus as shown in Fig. 1. Draw a line along the center of your paper and label it with an "X" at each end. Fasten your mirror to the block of wood and place the mirror on the paper so that the reflecting surface is aligned with the "X" line (see Fig. 1).

Place a pin about 5 centimeters in front of the mirror and label this point, "P" (see Fig. 2 on next page). Lay a ruler on the paper so that it is to the right of the pin and in front of the mirror. Look along the edge of the ruler at the image of the pin in the mirror (see Fig. 1, above). When the edge of the ruler is directly in line with the image of the pin, draw a line along the ruler edge (line A, Fig. 2). Use the same procedure to locate the image on the left side of the pin (line B, Fig. 2).

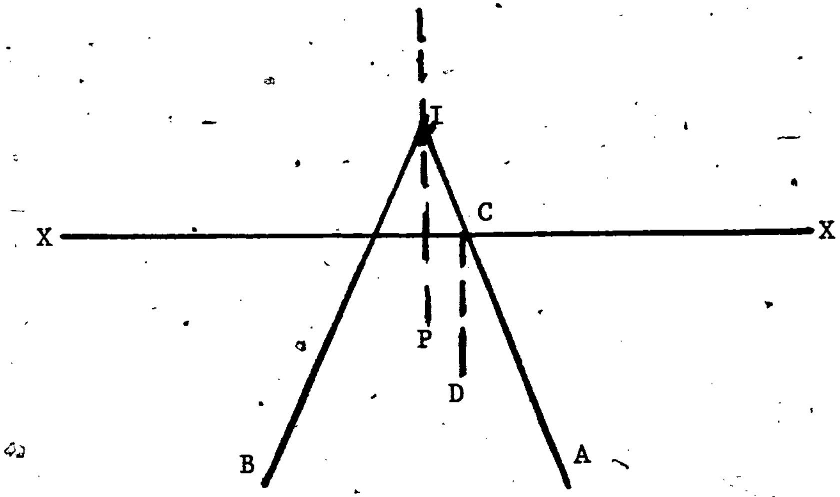


LOCATING THE IMAGE POINT (I)
Fig. 2

Remove the mirror and pin. Draw a line through "P" perpendicular to the "X" line. Extend this perpendicular a short distance beyond the mirror surface line ("X" line). Now extend the lines you have drawn on the left and right side of "P" until they intersect (behind the "X" line). Label this point, "I"; label the line on the right "IA" and on the left, "IB." Your drawing should look like Fig. 2.

Now, construct a perpendicular line, "CD," at the point where line, "IA" intersects the "X" line (see Fig. 3 on next page). Label this point of intersection "C." Draw a line between points, "P" and "C."

Show, by drawing arrows on line PC and CA, that a light ray going from point P toward C would first strike the mirror at point C and would then reflect from C back toward A.



LOCATING THE IMAGE POINT (I)
Fig. 3

With a protractor, measure the angle of incidence (PCD) and the angle of reflection (DCA); record these in your notebook in a table similar to this one:

Measure of Angle PDC = ______

Measure of Angle DCA = ______

The reflected ray is ______

The incident ray is ______

Now draw another "X" line on a fresh sheet of paper. Place the pin in front of the mirror's center, as before. Construct a line from P (pin position) to the mirror's center. Rotate the mirror about its center through an angle of 20^{o}. Starting at point P, construct an incident and reflected ray. Measure the angle between these two rays and compare the rotation angle with this angle. When the mirror was rotated, through what angle was the image displaced, as compared with the angle through which the mirror was rotated?

RESOURCE PACKAGE 2-1.2

REFLECTION II

DRAWING FROM A REFLECTION
Fig. 1

Sit in front of a mirror and attempt to draw the diagram below, looking <u>only</u> at the reflection of the diagram (see Figures 1 and 2). Write in your notebook a brief explanation of why this drawing is a difficult task.

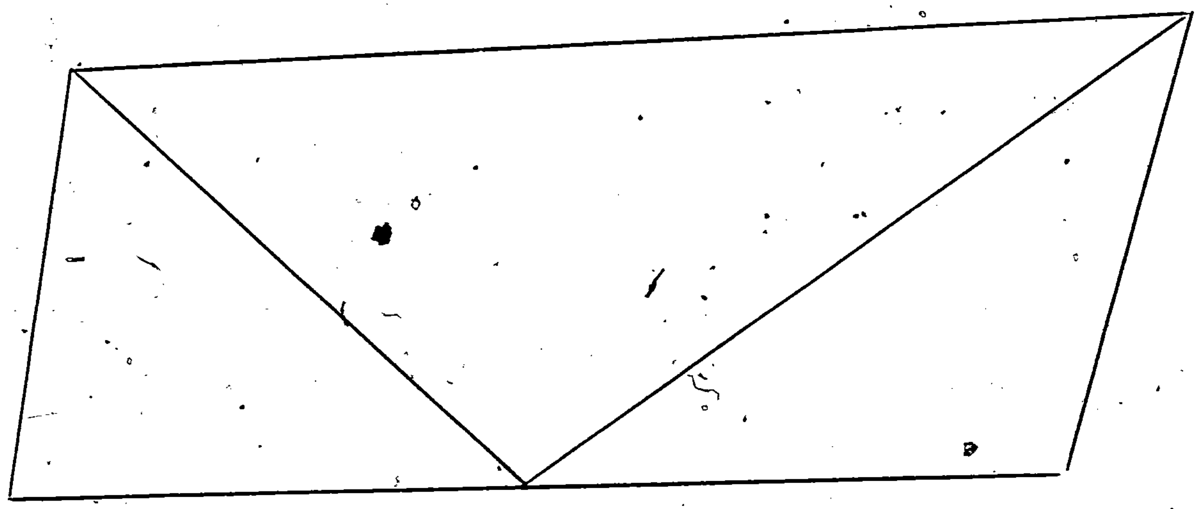


DIAGRAM
Fig. 2

RESOURCE PACKAGE 2-1.3

REFLECTION III

You have seen that light striking a plane mirror surface is reflected according to a law of reflection, (sometimes called the Law of Reflection); i.e., the angle of incidence (i) equals the angle of reflection (r), or i = r. Now, let's investigate how this law can be applied to the location of the image produced by a plane mirror.

INVESTIGATING THE LOCATION OF A PLANE MIRROR IMAGE

You will need:

same equipment listed in Resource Package 2-1.1 (see page 15)

Draw the "X" line across a large sheet of paper. Place the mirror on the line as was done in Resource Package 2-1.1. Draw an arrow on the paper about 6 to 7 cm in front of the mirror. Make the arrow about 2 cm long and slanted so that the head of the arrow is closer to the mirror. Stick a pin vertically into the head of the arrow and sight along the ruler's edge toward the head of the arrow's image (see Fig. 1).

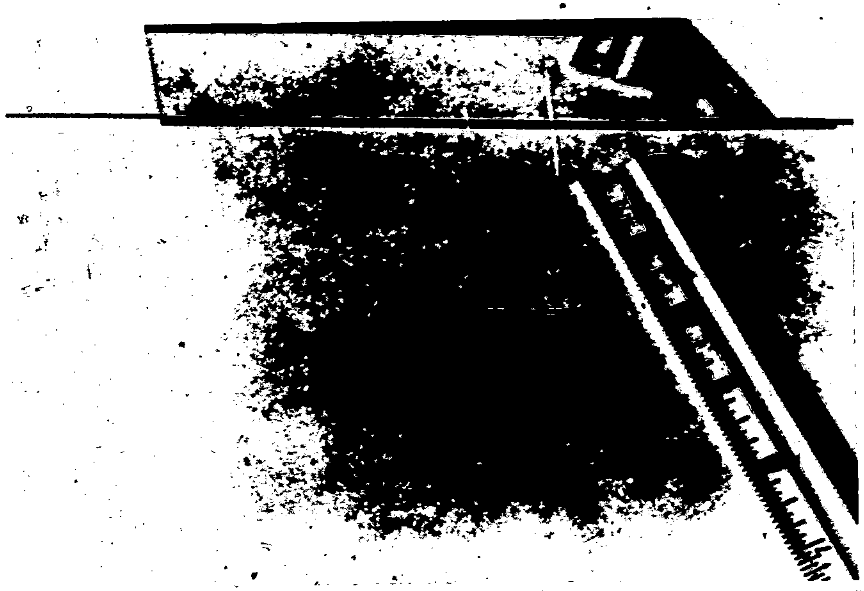


Fig. 1
LOCATING THE IMAGE

Draw a line along the edge of the ruler. Move the ruler to the other side of the arrow, and again sight at the image of the arrowhead. Draw another straight line (see Fig. 2).

Remove the pin and place it at the tail of the arrow. Repeat the preceding procedure used for the arrowhead, except this time draw two lines for the image of the tail. Remove the mirror from the paper. Extend each of the two lines (two for the image head, two for the image tail) until they intersect behind the mirror. Join these two intersection points with a straight line and indicate the head and tail of the image. Then draw a line connecting the head of the image to the head of the object and a second line connecting the tail of the image to the tail of the object.

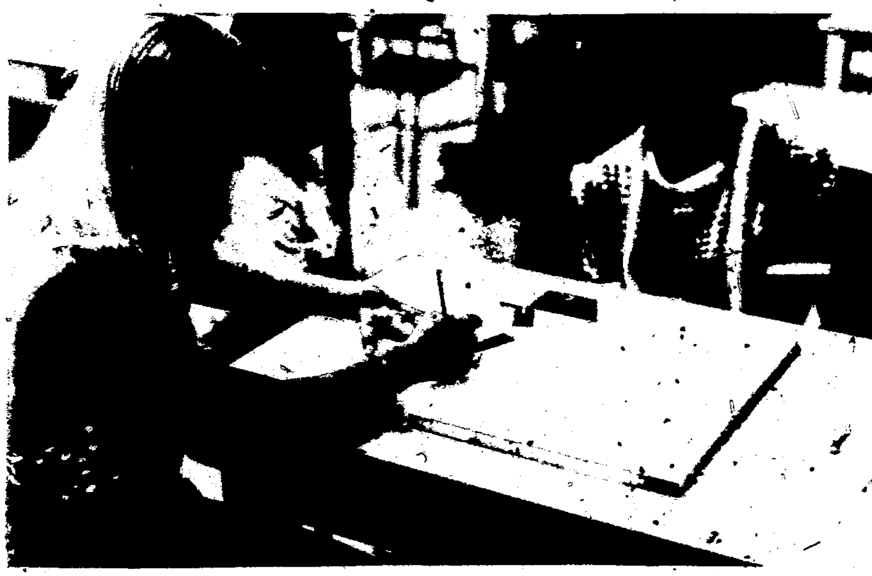


Fig. 2
LOCATING THE IMAGE

Distance of head of object to mirror = ________ cm

Distance of head of image to mirror = ________ cm

Distance of tail of object to mirror = ________ cm

Distance of tail of image to mirror = ________ cm

Length of object = ________ cm

Length of image = ________ cm

Write down a comparison of the size of the image and of the object. Describe the location of the image. Record the comparative distance from the mirror to the image and the object. Describe the type of image (real or virtual; inverted or erect; straight or perverted).

THOUGHT QUESTION

If you stand 10 meters from a mirror, how far are you from your image? If you walk toward a mirror at the rate of 3 meters/sec, how fast do you approach your image?

RESOURCE PACKAGE 2-1-4

REFLECTION IV

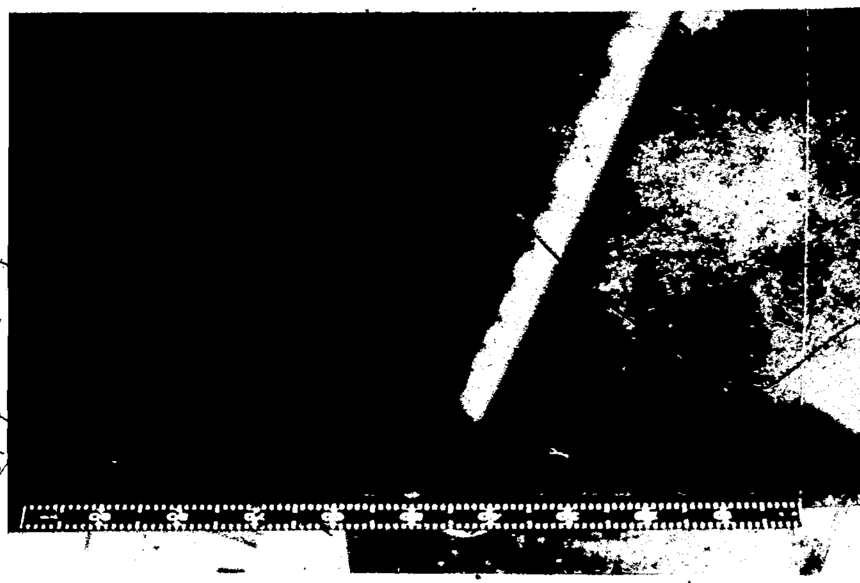
Light appears to travel in a straight line. For example, we can't see around corners. For our purposes, then, we can consider that light travels in a straight line, bending only if it travels from one medium to another (such as from air to water; from glass to plastic; etc.) or when it passes the sharp edge of an obstacle. Later, you will study the bending of light by a medium (refraction) and the bending of light by an obstacle (diffraction).

Let's consider the question, "What happens when light traveling through a first medium strikes a second medium?" Well, several things can happen:

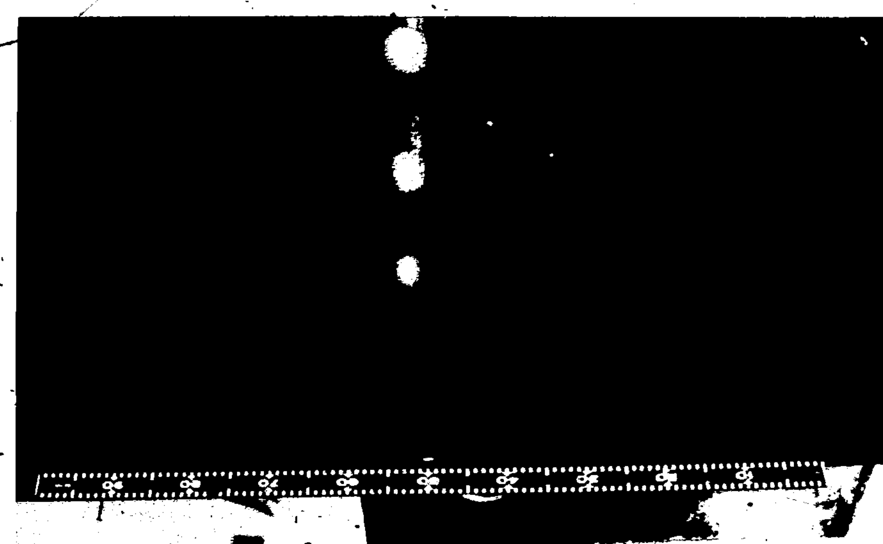
1. some light may be reflected;
2. some light may be refracted;
3. some light may be absorbed;
4. some light may be transmitted.

If it were not for the reflective properties of objects, our eyes would be of little use, because most objects we see are visible because of reflected light. Just by looking around right now, you can see how much vision depends upon light reflection; i.e., everything you can see is because of reflected light except for luminous objects (luminous means light producing, such as the sun, a candle, etc.).

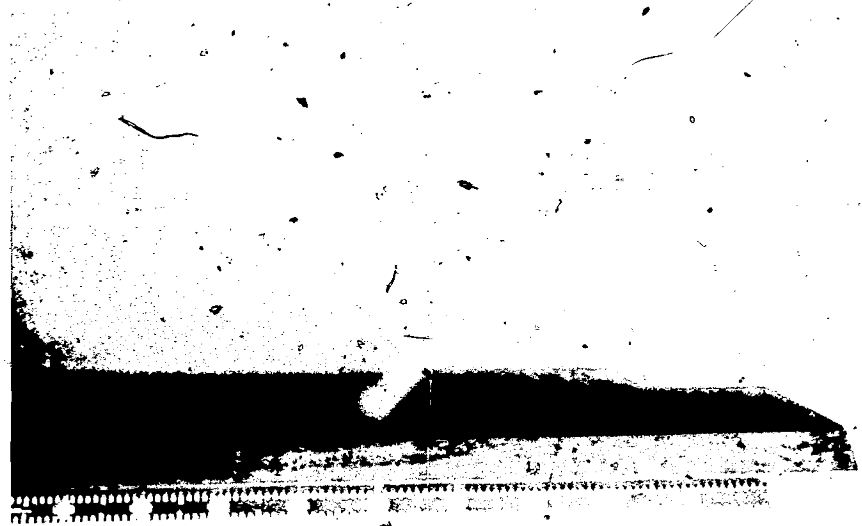
Let us first consider the phenomenon of reflection. Reflection is the bouncing back of light from an object. Light <u>beams</u> are frequently considered to be made up of "bundles" of lines of light called <u>rays</u>; therefore, the path of a single ray can be used to represent the path of the entire beam. The reflection of light tends to follow the same rules that govern the reflection (bouncing) of a golf ball off the side of a hard, smooth board. Look at the pictures on this page and page 27 (Fig. 1 through 3). Can you predict where the golf ball will go after it strikes the board?



ANGLED BOUNCE
Fig. 1



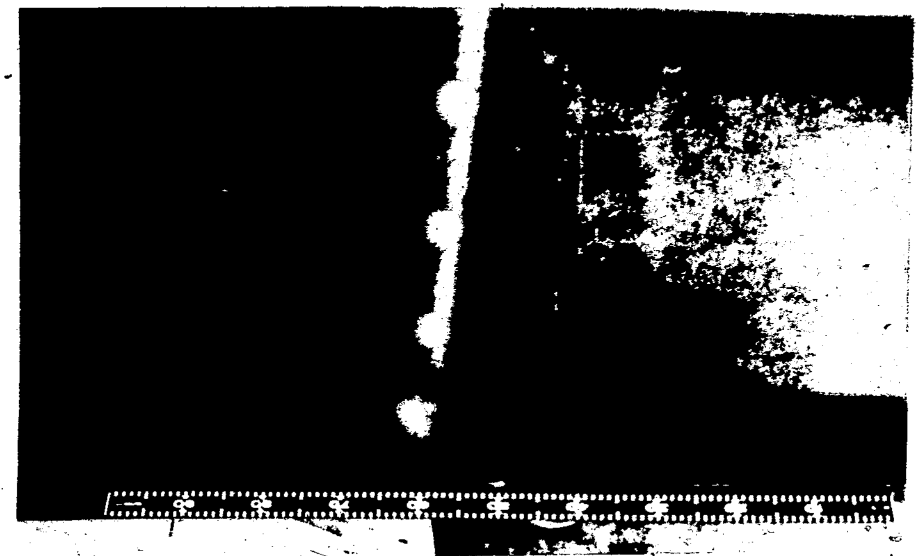
HEAD-ON BOUNCE
Fig. 2



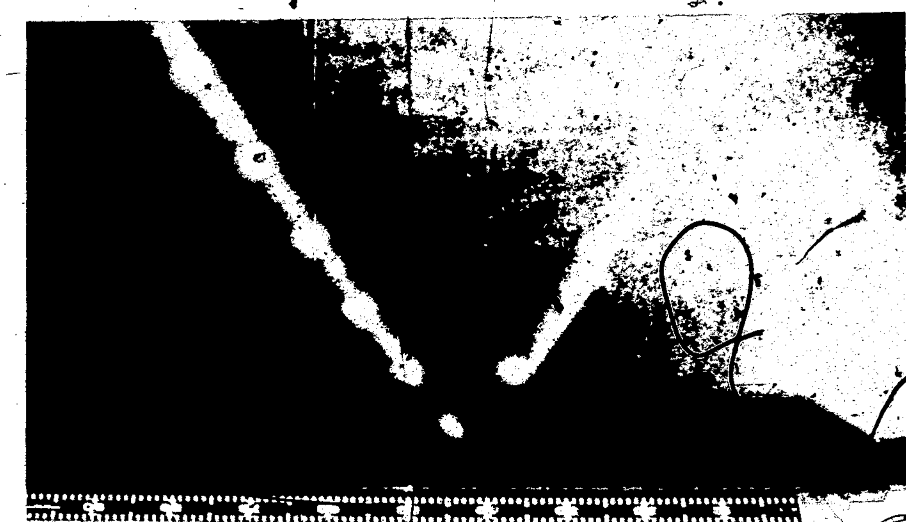
OBLIQUE BOUNCE
Fig. 3

Now turn to page 29 and examine Fig. 4, 5, and 6. Do the pictures agree with your predictions? Would you expect the same results with a rough surface?

ANGLED BOUNCE
Fig. 4



HEAD-ON BOUNCE
Fig. 5



OBLIQUE BOUNCE
Fig. 6

Now consider a plane mirror instead of the board. A line drawn perpendicular to the mirror surface is called the <u>normal</u> (see Fig. 7 on page 31). A light ray moving parallel to the normal strikes the reflecting surface and returns by the same path, just as a golf ball does when striking a smooth board head-on.

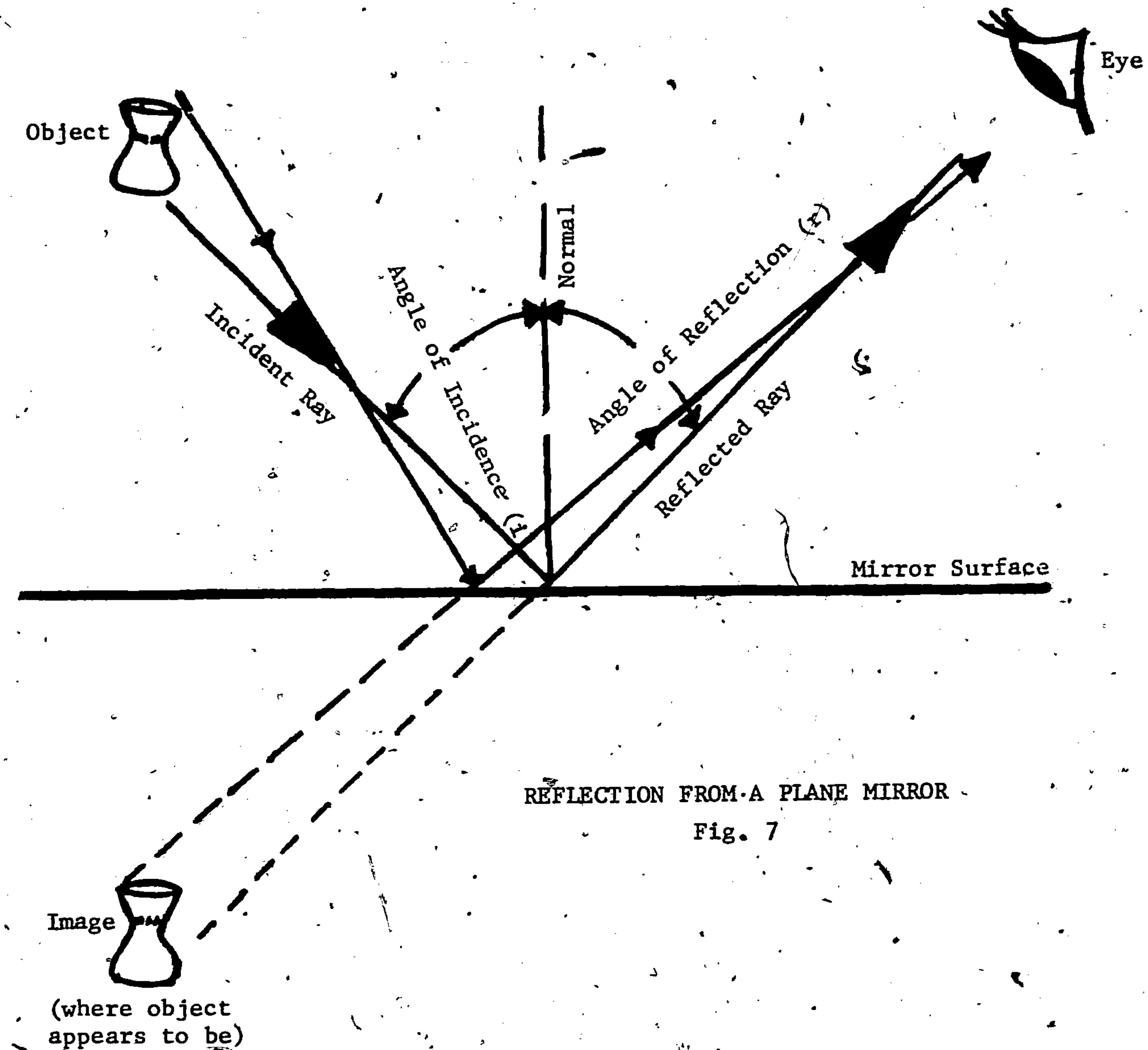
However, if a ray strikes a reflecting surface <u>obliquely</u> (NOT at right angles to; not normal to the reflecting surface), it necessarily strikes at some angle to the normal and then reflects, returning on the opposite side of the normal.

The incident ray (the ray moving toward the surface), the normal, and the reflected ray all lie in the same plane. The angle between the normal and the incident ray is called the <u>angle of incidence</u> (<u>i</u>); the <u>angle of reflection</u> (<u>r</u>) is the angle between the normal and the reflected ray. Notice that the location of the normal is dependent upon where the incident ray strikes the surface.

Experiments show that the angle of incidence (<u>i</u>) always equals the angle of reflection (<u>r</u>). This can be expressed mathematically as:

$$i = r.$$

For both rough and smooth surfaces, the angle of incidence equals the angle of reflection (see Figs. 8 and 9 on page 32).



REFLECTION FROM A PLANE MIRROR

Fig. 7

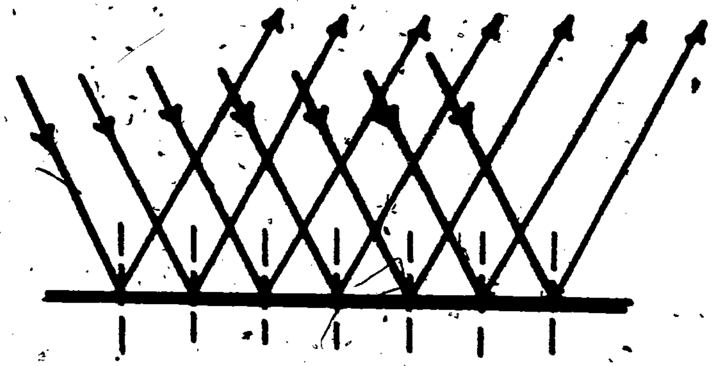


Fig. 8
SPECULAR REFLECTION

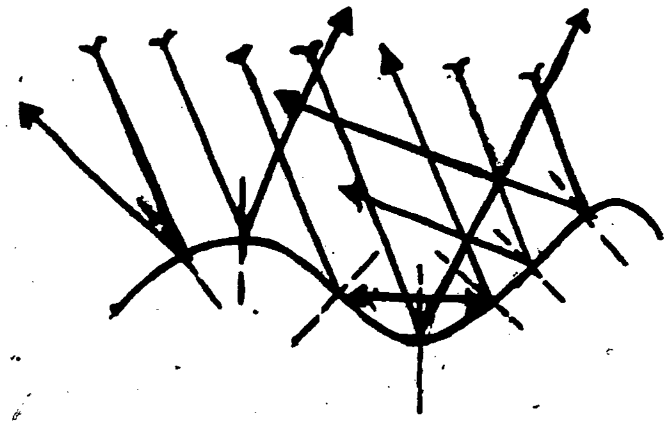


Fig. 9
DIFFUSED REFLECTION

Reflection obtained from a smooth surface is known as <u>specular reflection</u> (the Latin word for mirror is <u>speculum</u>). The reflected beam is sharply defined in such a reflection because parallel incident rays are reflected as parallel rays. However, most natural surfaces are rough; and from them we get <u>diffused</u> reflection (see Fig. 9). Consider the reflective surface of this paper. The reflected light is scattered in various directions, even though the incident rays may be parallel (see Fig. 10 on page 33).

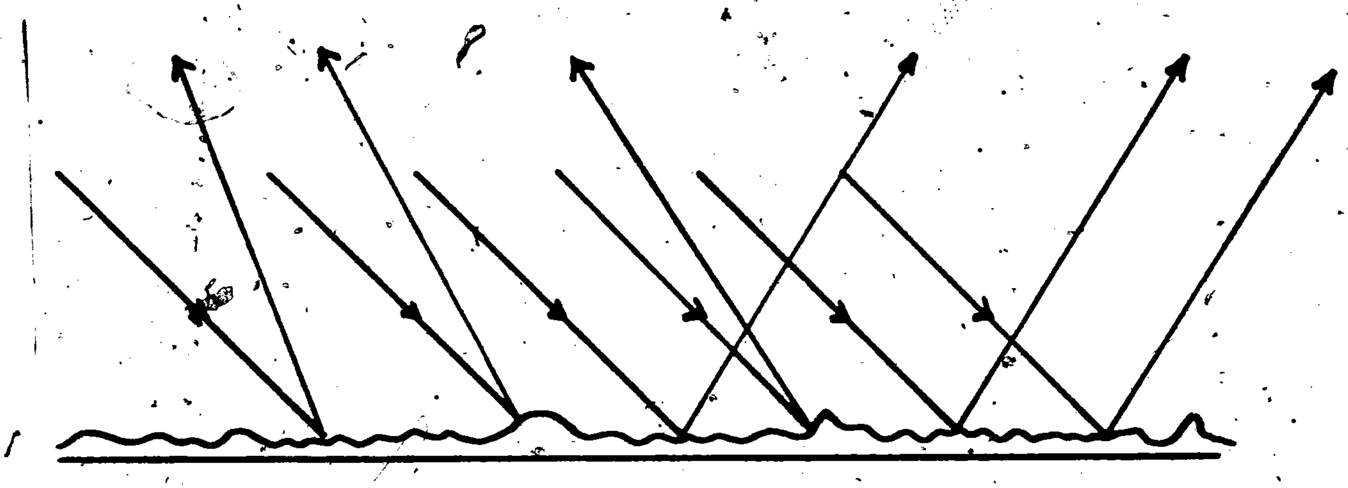


Fig. 10
LIGHT SCATTERING FROM PAPER SURFACE

INVESTIGATING SPECULAR AND DIFFUSED REFLECTION

You will need:

- light meter
- light source and reflector
- six sheets of white paper of different surface textures

Set up the apparatus as shown in Fig. 11 (see page 34). Use a darkened room, so that the light meter receives only light reflected from the paper. Slowly change the reflector angle until the light meter value is maximum; this maximum is the value you are to record. Make a data table and record the light meter values for each surface in your notebook.

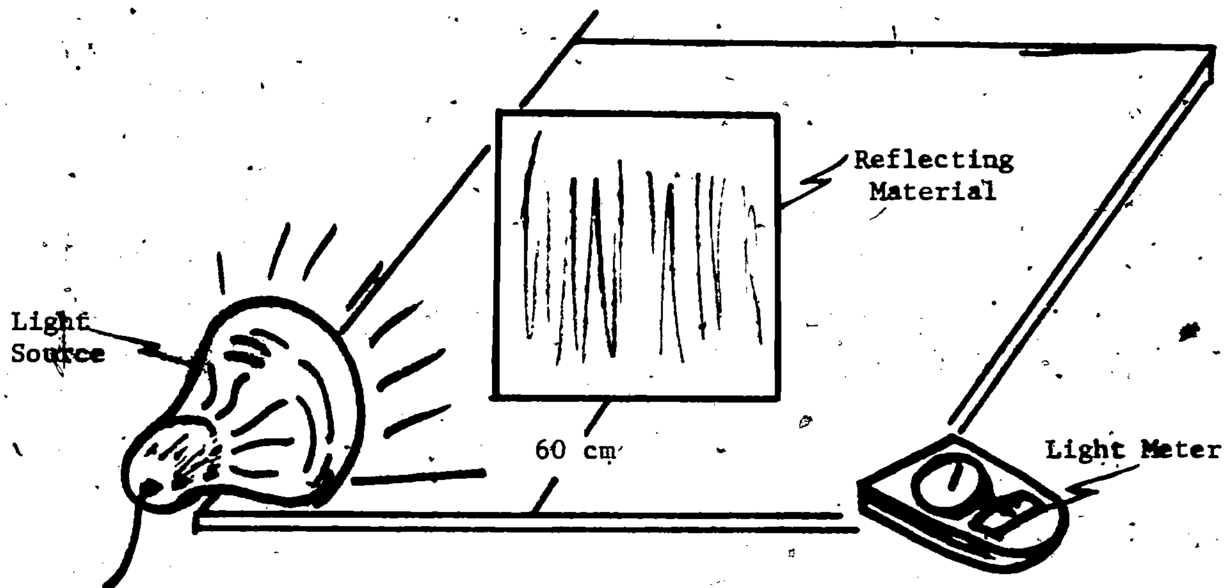


Fig. 11
INVESTIGATING REFLECTION

Now try to determine if there is a relationship between the amount of light reflected and the texture of the reflecting surface. Start with the smoothest surface and progress to the roughest. When you read the maximum meter values, you should have detected a positional relationship between the source, the meter, and the reflecting surface. Describe this relationship in your notebook.

INVESTIGATING PLANE MIRROR REFLECTIONS

You will need:

plane mirror

opaque object

Observe the characteristics of the object's image in a plane mirror:

1) The image appears the same size as the object.

2) The image appears erect (upright; <u>not</u> inverted).

3) The image appears as far behind the mirror as the object is in front of the mirror.

4) The image is <u>virtual</u>. A virtual image is defined as one formed by rays which do <u>not</u> actually pass through the image position. This means that if a screen were placed at the position of the image (behind the mirror), no image would be seen on the screen, because no light rays actually get to the image position.

5) The image is reversed right to left (<u>perverted</u>); this is sometimes termed a <u>mirror image</u>. Notice that although perverted, a plane mirror image is not inverted; the mirror does not reverse up and down. This statement, of course, assumes a vertical mirror and the viewer in the normal upright position.

RESOURCE PACKAGE 2-1.5

MIRROR, MIRROR, ON THE WALL
ARE YOU TOO SHORT? ARE YOU TOO TALL?

Imagine that you have been promoted to manage the Clothing Department of Beiman Snarcus. The department's only mirror was broken by a bad image last week, and you have the task of buying a new mirror. As a matter of record, it was probably good that the old mirror was broken, because many customers complained of its not being tall enough for them to see themselves from head to toe. The old mirror was 5 feet tall.

Consider that fellow students in this physics class represent a cross section of the customers who would visit the Clothing Department of Beiman Snarcus's Store. Based on such height data, what would be the smallest mirror you would have to buy? Were the customers' complaints about the old mirror's being too short justified?

TO SOLVE THE PROBLEM:

Draw a diagram in your notebook and use ratios, ray diagrams, or whatever, to arrive at a solution. The mirror and the customer's height will not be the same. A diagram such as the one on page 38 might help.

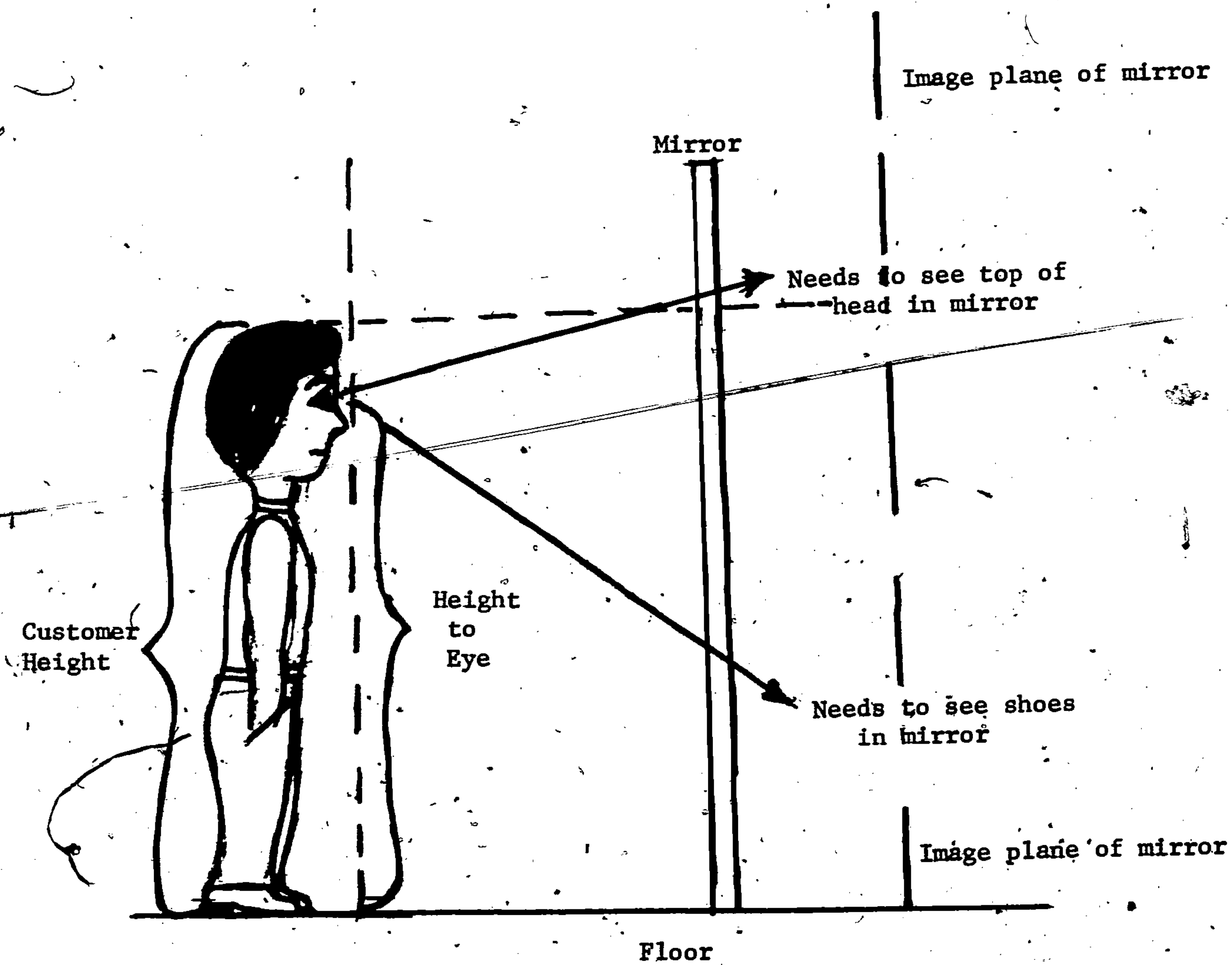


Image plane of mirror
Mirror
Needs to see top of head in mirror
Customer Height
Height to Eye
Needs to see shoes in mirror
Image plane of mirror
Floor

RESOURCE PACKAGE 2-1.6

IMAGE PROBLEM

Imagine that the Board of Directors of Beiman Snarcus, a small discount store, promote you to work as manager of the Shoe Department. Also, they increase the Department's budget by $167.73--enough to buy two plane mirrors. Along with this promotion, you are given the following problem: to determine how to fit together, at some angle(s), the two plane mirrors such that they will show any desired number of images ("n" images, where n = 1, 2, 3, ...) and to derive a formula that can be programmed into the Department's mini-computer, which will enable your employees to determine quickly the proper setting of the angle between these two mirrors to produce the desired number of customer images. If successful, the customer will be able to see as many images of the beautiful Beiman Snarcus shoes as your salesman feels necessary to close a sale.

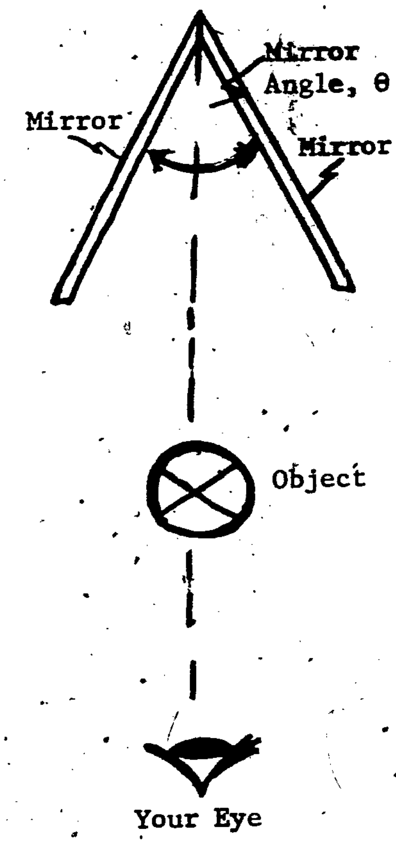
HOW TO SOLVE THE PROBLEM:

Make a table in your notebook like the one shown on the next page. Determine the angle between the two mirrors. Then see if you can derive a formula such that knowing the angle (θ), one can obtain the number of images (n). Then rearrange the formula so that if one knows the number of images, one can determine the angle for setting the mirror.

Hint: You should use 360° in the formula. Use two plane mirrors, a protractor for measuring mirror angles, and an object placed on a line bisecting (cutting in half) the mirror angle, as shown below.

TABLE

Number of Images (n)	Angle Between Mirrors (θ)
1	
2	
3	
4	
5	
...	
...	



Do you think that the mirrors can be arranged so that an infinite number of images can be produced?

RESOURCE PACKAGE 2-1.7

SOME APPLICATIONS

There are many careers involved in making designs for wallpaper, fabrics, and rugs. An instrument often used to aid in developing these designs is a kaleidoscope. A kaleidoscope is a mirror device that makes use of multiple reflections.

A kaleidoscope consists of two plane reflecting surfaces set at an angle and placed within a tube. Pieces of colored glass, or other bits of colored material, are illuminated through a translucent glass at one end of the tube; and the other end has a peephole.

INVESTIGATING THE KALEIDOSCOPE

You will need the following materials:

- cardboard tube, about 2 in (5 cm) diameter and about 12 in (30 cm) long
- aluminized film sheets or small mirrors
- clear plastic film
- colored objects

Cut the aluminized film into two sections small enough to be taped together at a 60-degree angle and to fit inside the entire length of the tube (see Fig. 1 on page 42). In your notebook show the calculation for how many images you will expect to see (use the formula from Resource Package 2-1.6).

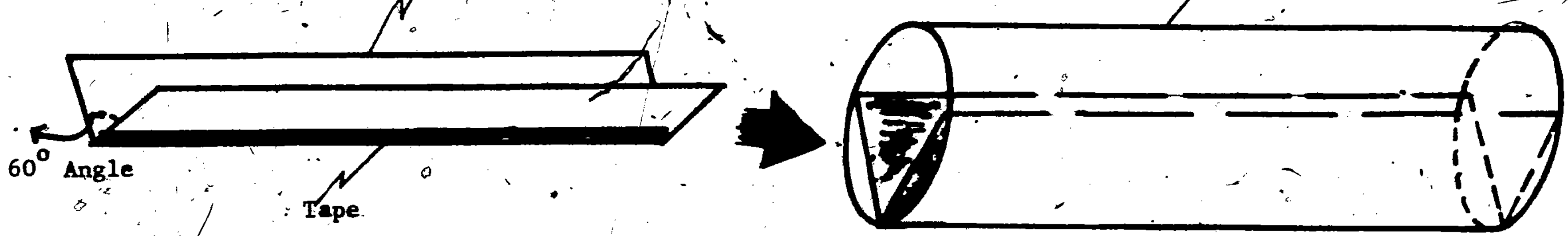


Fig. 1
BUILDING A KALEIDOSCOPE

Over one end of the tube, place a cap with a small hole in the center (peephole). The cap for the other end should contain the colored objects, sandwiched between an outer layer of translucent film and an inner layer of clear film. The distance between the two films should allow the free movement of the colored objects.

An interesting effect can be produced by placing a lens (a bi-convex or "burning glass" lens) in place of the colored objects; this method produces images of the environment. A magician or stage performer can make special use of plane reflecting surfaces to achieve startling effects or to perform feats of magic. For example, the appearance of a ghost on a dimly lit stage can be accomplished, as shown in Fig. 2 (see page 43).

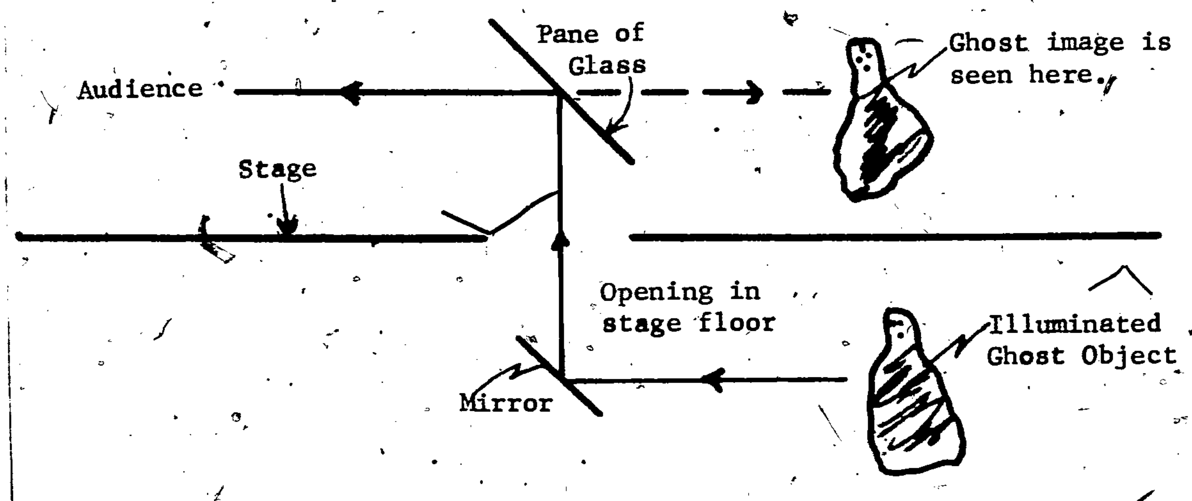


Fig. 2
CATCHING A GHOST

The audience must be in darkness and the stage lighting must be dim to conceal the glass pane in order for this trick to work properly. The actors perform behind a large pane of glass, set at an angle of 45 degrees with the vertical. Another pane of glass or mirror, set at 45 degrees, is concealed below the stage or in the pit. The "ghost" stands in front of the concealed glass; the subject is illuminated and light reflects from her/him to the lower sheet of glass, then to the upper sheet, and then to the audience.

If the lower reflecting surface is a mirror instead of a sheet of glass, the ghost will appear much brighter. The lighting on the stage must be carefully controlled to make the actors visible to the audience and yet keep the glass invisible.

Another use of plane mirrors is to show a head on a platter. Two large mirrors, a platter with a hole large enough for someone's head to fit through, a three-legged table, and a stage properly fitted with drapes are all you need for this trick. The two mirrors are fitted in place at an angle so that their edges are concealed by the legs of the table. The drapes are hung so that they reflect in the mirrors and so that they seem to blend in with similar drapes in the background. The audience thinks they are looking through the legs of the table at the background drapes. The subject, whose head is to be presented to the audience, is concealed behind the mirrors. She/he puts her/his head through the hole in the platter before the scene is presented to the audience. With the proper effects and acting, the results can be gruesome and impressive when the curtains are drawn.

In your notebook sketch the old head-on-a-platter trick. Use the old ghost-on-a-stage trick as a guide.

RESOURCE PACKAGE 2-2.1

REFLECTION EXERCISE

Using the figure below, see if you can answer the following questions. Write your answers in your notebook.

1) The incident ray is line _____.

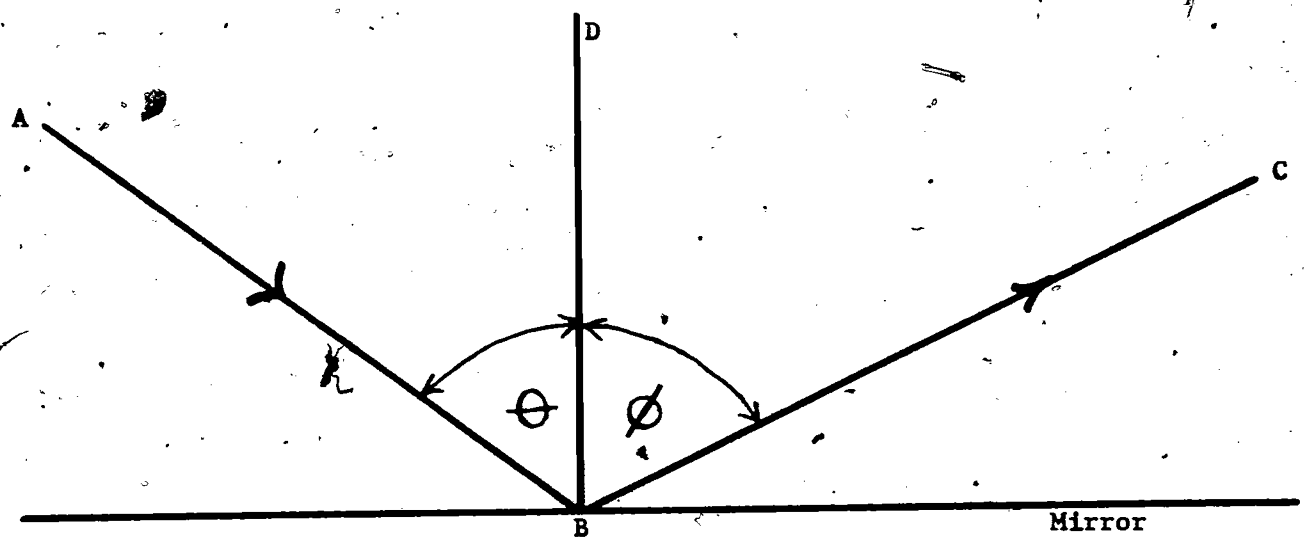
2) The normal is line _____.

3) The reflected ray is line _____.

4) The angle of incidence is _____.

5) The angle of reflection is _____.

6) List some properties of the image.



RESOURCE PACKAGE 2-2.2

ANSWERS

1) AB

2) DB

3) BC

4) ABD, or $\ominus$

5) DBC, or $\varnothing$

6) virtual
erect (upright)
perverted (reversed left and right)
same distance behind mirror as subject is in front

RESOURCE PACKAGE 3-1.1

CURVED MIRROR INVESTIGATION

You will need the following:

- cylindrical mirror
- wooden drawing board
- drawing compass
- ruler or straight edge
- straight pins

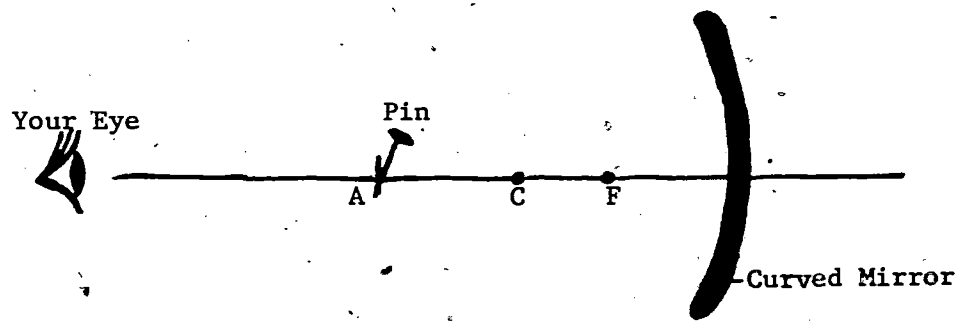


Fig. 1
INVESTIGATING A CURVED MIRROR

43

Place the curved edge of a curved mirror on a flat sheet of paper, with the curved surface facing you. Trace the outline of the mirror on the paper and locate the middle of the arc. Using a compass, locate the center of curvature and mark it "C." Draw a line through C and the middle of the outline of the mirror. This line is on what is called the mirror's <u>principal axis</u>. Locate the principal focus and label it "F"; this is the point where incident parallel light rays will focus. At a point beyond the center of curvature (C), draw a short line perpendicular to the principal axis; place a pin at this spot and label the spot "A"(see Fig. 1, above). By sighting along the edge of a ruler, locate the image of the pin (see Fig. 2 on page 50). Draw a straight line and repeat the process on the other side of the pin. Extend the sight line to intersect with the principal axis; this is the location of the image. If intersection does not occur on the axis, repeat your sightings.

You have been working with what is called a <u>con-verging mirror</u>. What can you say about the location and nature of the image?

Next, draw a horizontal arrow across a folded sheet of paper about 2 cm long; place the paper where the pin was located, with the arrow facing the mirror. Observe the image and compare it with the object (erect? inverted? - smaller? same size? larger?)

INVESTIGATING A CURVED MIRROR
Fig. 2

Now place the pin between points C and F. Make sightings on both sides of the principal axis and locate the image as before. Next, place the horizontal arrow at this new point and determine the characteristics of the image. Do the same for a location between the principal focus and the mirror. Record your observations in your notebook; make a chart similar to the one on page 51.

CHART

Location of Object	Real or Virtual	Location	Inverted or Erect	Equal Size, Larger, or Smaller
Beyond C				
Between F and C				
Between F and Mirror				

This time turn the mirror around so that it operates as a so-called <u>diverging mirror</u>. Locate the principal axis, the center of curvature, and the principal focus. Draw an arrow on the principal axis on the curved side of the mirror. Place a pin at the head of the arrow, and make sight lines on both sides of the principal axis. Then place the pin on the tail of the arrow and repeat the same procedure for making sight lines.

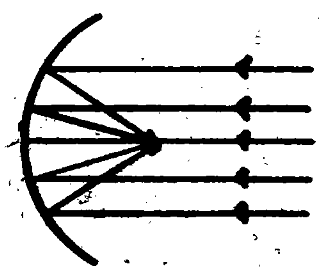
After removing the pin and mirror, extend the sight lines for each pin position until they meet. Draw the image that represents the arrow through these two points. In your notebook, describe what you expect will happen to the general characteristics of the image as the distance of the object is changed?

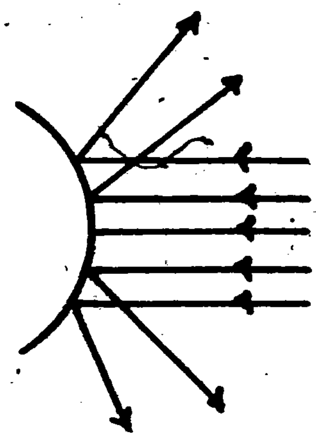
RESOURCE PACKAGE 3-1.2

CURVED MIRRORS

A reflecting surface need not be flat to exhibit specular reflection. The mirror can be curved, but it must be smooth.

The law of reflection for a single ray is the same for curved mirrors as it is for plane mirrors. However, the overall effect of a number of parallel incident rays can be quite different. Curved mirrors do not have the same imaging properties as plane mirrors. Parallel rays reflected from a curved surface are no longer parallel. If the reflecting surfaces are spherical, the reflected rays of light either converge to a single point or diverge away from the reflecting surface. Thus, curved mirrors are classified as either converging or diverging mirrors.



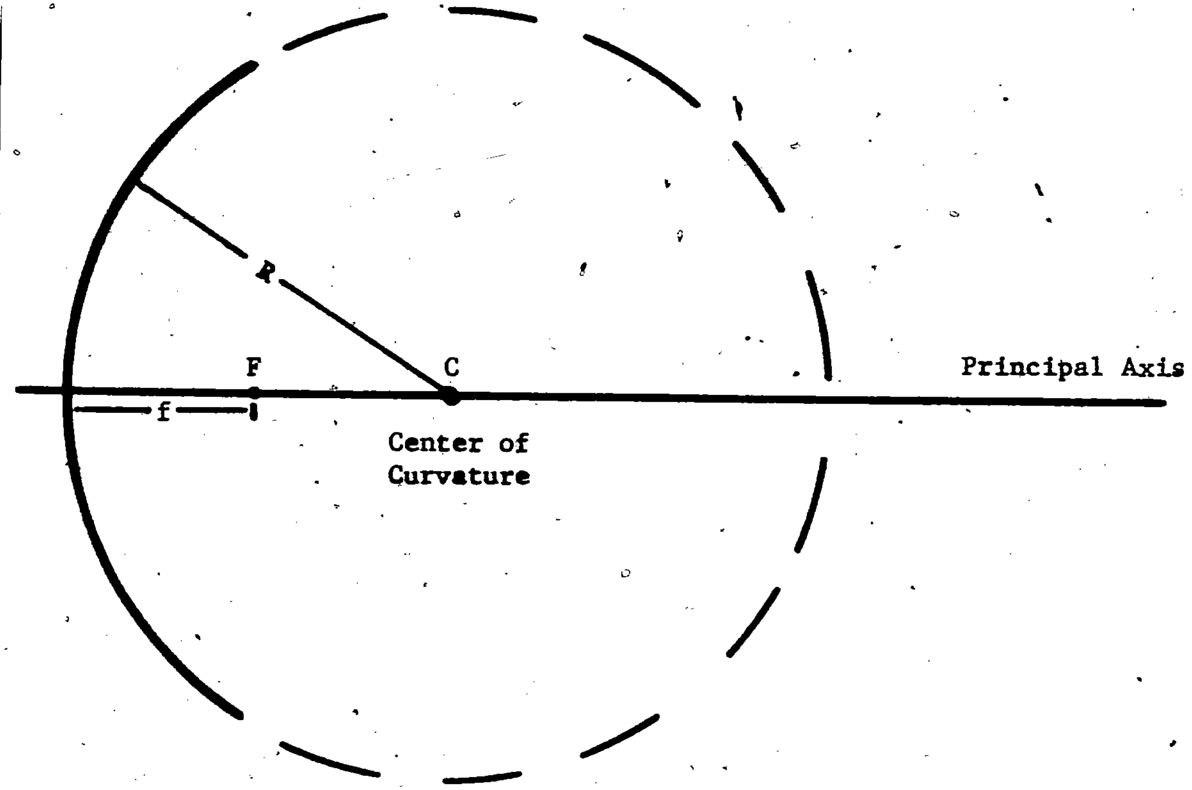


Curved mirrors usually take the shape of a sphere, a paraboloid, an ellipsoid, or a cylinder. All such mirrors have converging or diverging properties.

Can you determine which is a converging mirror and which is a diverging mirror in the pictures below?

List some differences in the image they produce.

To study curved surfaces, you first need to know some basic vocabulary. Examine the mirror sketched on page 55. This mirror is made from a section of a sphere, so it would be called a <u>spherical mirror</u>. Try to relate the definitions to the sketch.



1) Principal focus (F) - a point through which light rays parallel to the principal axis are reflected.

2) Principal axis - line through center of curvature and center of mirror.

3) Center of curvature (C) - the center of a spherical shell.

4) Radius of curvature (R) - the radius of a circle to which a given curve corresponds.

5) Focal length (f) - the distance between the principal focus of the mirror and its surface; for a spherical mirror, $f = \frac{R}{2}$.

6) Convex reflecting surface - causes divergence of parallel light rays.

7) Concave reflecting surface - causes convergence of parallel light rays.

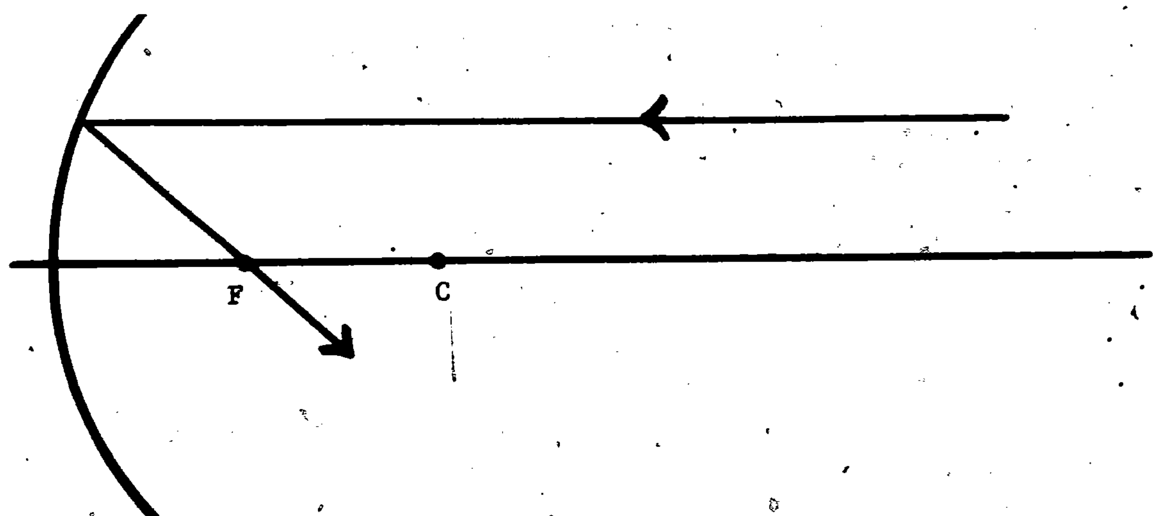
8) Spherical aberration - the defect or inability of all spherical mirrors to bring parallel light rays to the same focus on the principal axis.

9) Real image - an image that can be focused on a screen.

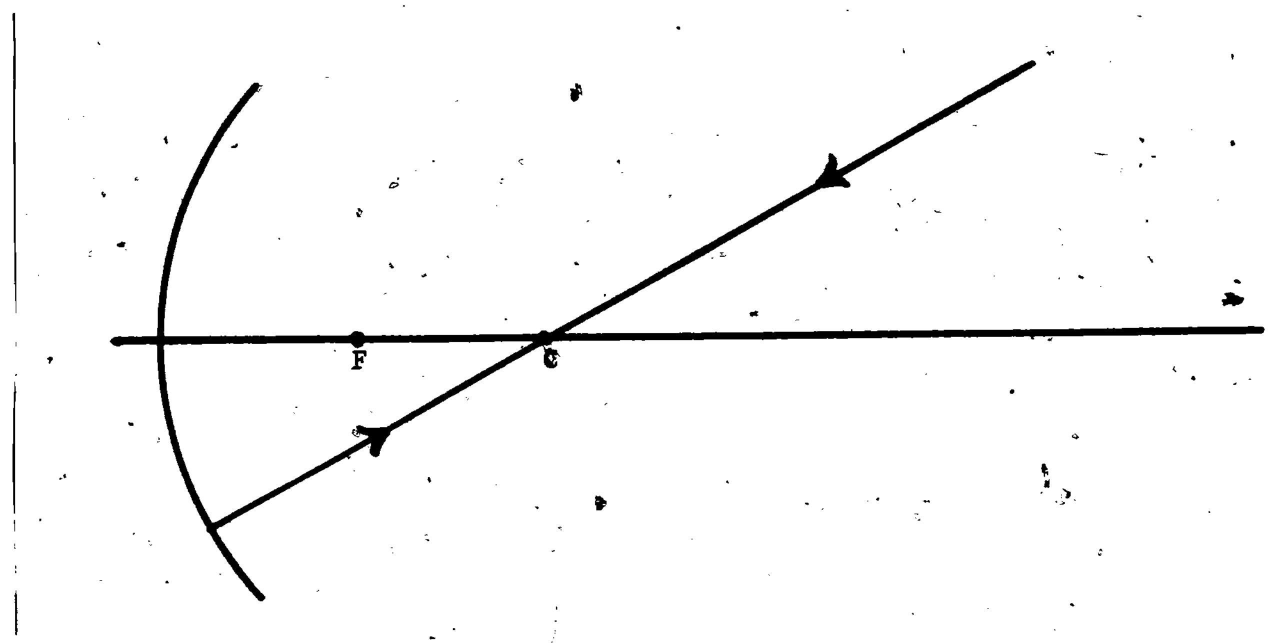
10) Virtual image - an image that can be seen by the eye but cannot be formed on a screen.

Curved mirrors can be studied by the ray method of constructing images. In the following discussions, spherical aberration will be neglected and ray properties will be used. The ray properties are as follows:

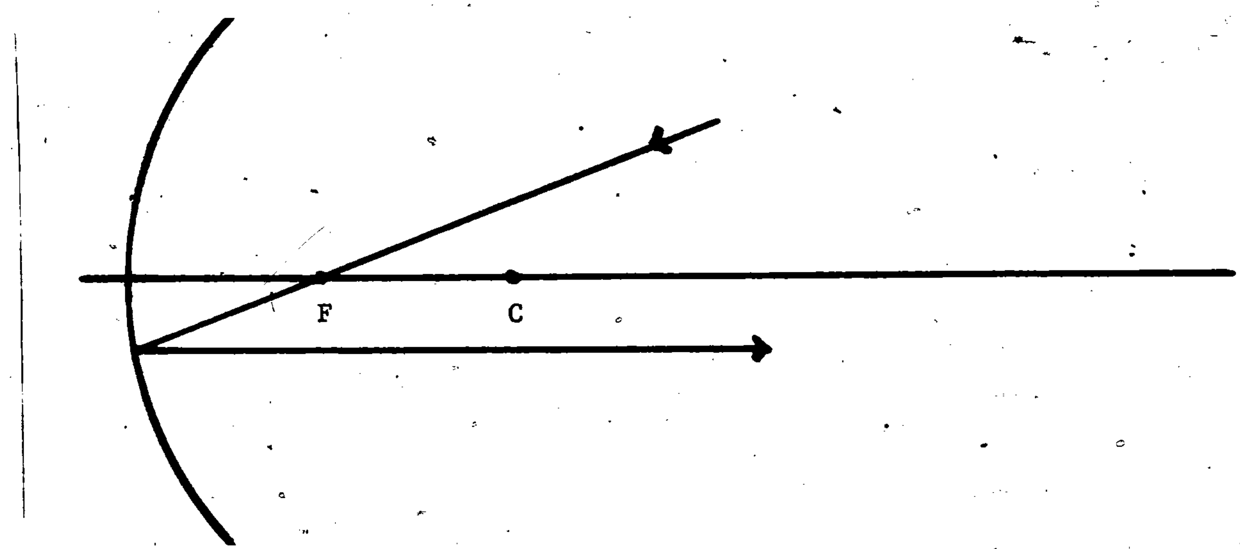
1) A ray of light traveling parallel to the principal axis is reflected through the focus (f).



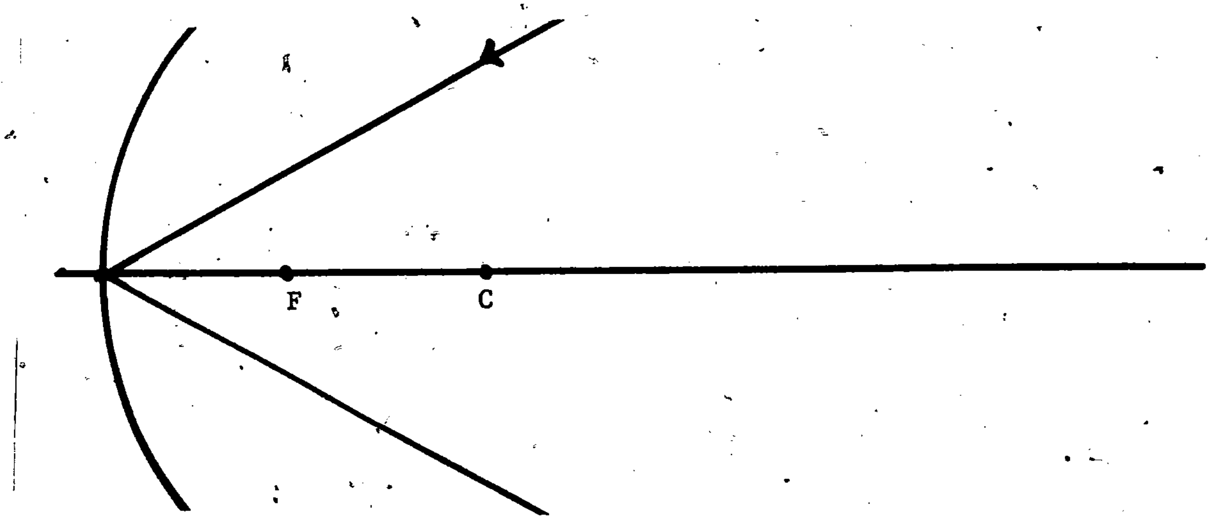
2) A ray of light which passes through the center of curvature (C) and which is incident perpendicular to the mirror's surface, is reflected back through C.



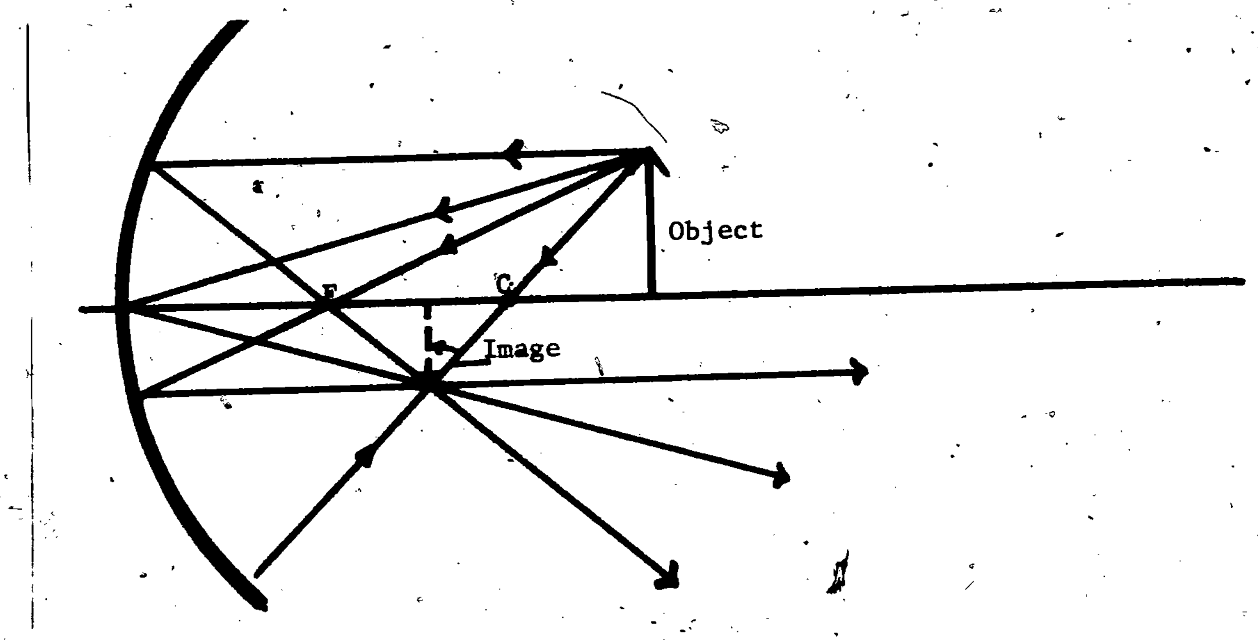
3) A ray of light passing through the focus (f) is reflected so that it is parallel to the principal axis.



4) A ray which strikes at the intersection of the principal axis and the mirror will be reflected so that it makes an equal angle with the principal axis. If the light ray travels down the principal axis, it is reflected back along the principal axis.



The intersection of all (or even of <u>any two</u>) of the reflected rays locates the image point; see how these rays can be combined, as in the sketch below:



Experiments show that the distance of the object (d_o) and the distance of the image (d_i) from the mirror, the size of the object (S_o) and size of the image (S_i), and focal length are related as follows:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad \text{and} \qquad \frac{S_o}{S_i} = \frac{d_o}{d_i}$$

These formulas can be arranged to find the following properties, when others are known:

1) distance of object (d_o)

$$d_o = \frac{d_i \times f}{d_i - f} \qquad d_o = \frac{S_o \times d_i}{S_i}$$

2) distance of image (d_i)

$$d_i = \frac{d_o \times f}{d_o - f} \qquad d_i = \frac{S_i \times d_o}{S_o}$$

A negative (-) d_i represents an image on the other side of the mirror.

3) focal length (f)

$$\frac{1}{f} = \frac{d_o + d_i}{d_o \times d_i}$$

4) size of object (S_o)

$$S_o = \frac{d_o \times S_i}{d_i}$$

5) size of image (S_i)

$$S_i = \frac{d_i \times S_o}{d_o}$$

Example Problem 1:

A converging mirror whose focal length is 20 cm is placed 30 cm from an object which is 4.0 cm high. Calculate the location of the image (d_i) and the height of the image (S_i).

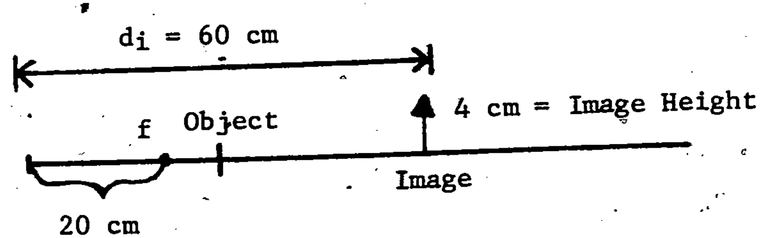
$f = 20$ cm

$d_o = 30$ cm

$S_o = 4.0$ cm

$d_i = ?$

$S_i = ?$



$$d_i = \frac{d_o \times f}{d_o - f}$$

$$= \frac{30 \text{ cm} \times 20 \text{ cm}}{30 \text{ cm} - 20 \text{ cm}}$$

$$= \frac{600 \text{ cm} \times \text{cm}}{10 \text{ cm}}$$

$$d_i = 60 \text{ cm}$$

$$S_i = \frac{d_i \times S_o}{d_o}$$

$$= \frac{60 \text{ cm} \times 4.0 \text{ cm}}{20 \text{ cm}}$$

$$= \frac{240 \text{ cm} \times \text{cm}}{20 \text{ cm}}$$

$$S_i = 12 \text{ cm}$$

Thus, the image is 60 cm from the mirror and is enlarged to a height of 12 cm. (You should always diagram a problem solution of this kind, as was done above.)

Example Problem 2:

A converging mirror whose focal length is 20 cm is placed 5.0 cm from an object which is 5.0 cm high.

Calculate the location of the image (d_i) and the height of the image (S_i).

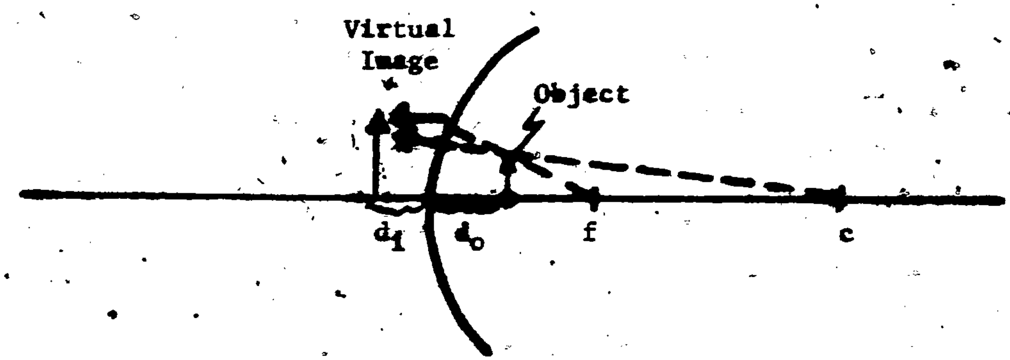
$f = 20$ cm

$d_o = 5.0$ cm

$S_o = 5.0$ cm

$d_i = ?$

$S_i = ?$



$$d_i = \frac{d_o \times f}{d_o - f}$$

$$= \frac{5.0 \text{ cm} \times 20.0 \text{ cm}}{5.0 \text{ cm} - 20.0 \text{ cm}}$$

$$= \frac{100.0 \text{ cm} \times \text{cm}}{-15 \text{ cm}}$$

$d_i = -6.65$ cm (The negative sign (-) indicates that the image is behind the mirror, and it also indicates that the image is erect*.)

$= \frac{d_i \times S_o}{d_o}$ (Since size cannot be a negative number, you must use a positive (+) 6.65 for d_i.)

----

* Or, you can just remember that for a concave mirror, if d_o is less than f, the image is ALWAYS erect, enlarged, and virtual; if d_o is greater than, or equal to, f, the image is real and inverted. Convex mirrors produce ONLY virtual, erect, and enlarged images.

$$= \frac{6.65\ \text{cm} \times 5.0\ \text{cm}}{5.0\ \text{cm}}$$

$$= \frac{33.75\ \text{cm} \times \text{cm}}{5.0\ \text{cm}}$$

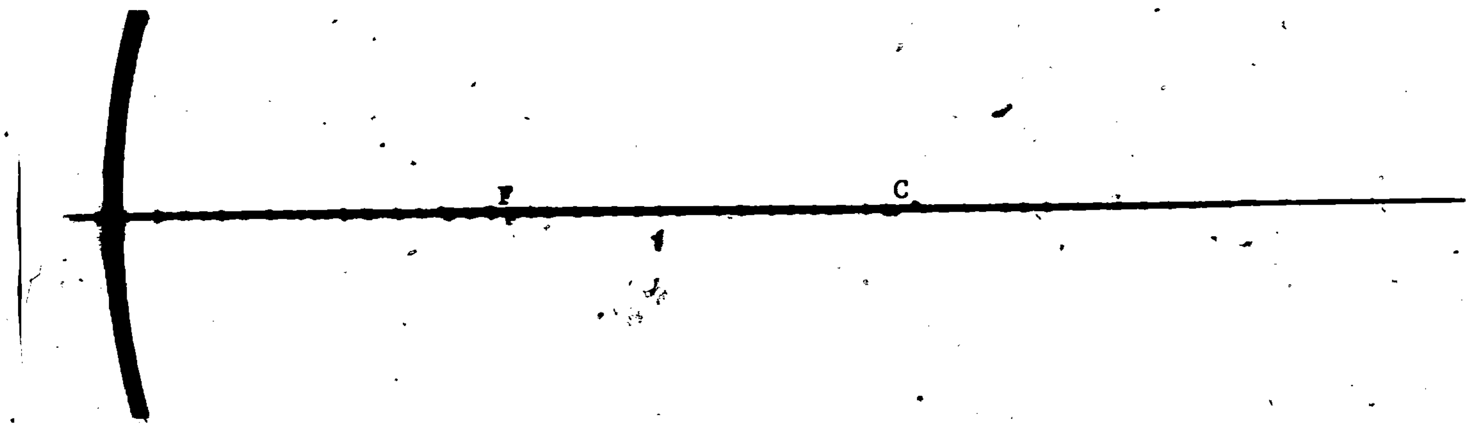
$$S_o = 6.65\ \text{cm}$$

Therefore, the image is 6.65 cm behind the mirror and the image is enlarged to a height of 6.65 cm.

RESOURCE PACKAGE 3-1.3

RAY CONSTRUCTION

Draw the figure as shown below on four different sheets of paper.



On each paper, use the different object locations listed below. When drawing the object, make sure that the "object" line is perpendicular to the principal axis; use the method outlined in Resource Package 4-1.1, page 47, and construct the image of an arrow 3.0 cm long at the following locations:

1) 13 cm
2) 11 cm
3) 8 cm
4) 2 cm

Also, on each sheet of paper, make a chart like the one shown on page 66. Measure the image distance and the image size and record these data.

Data	Measured	Calculated
Focus	6 cm	
Distance of Object	cm	
Distance of Image	cm	
Size of Object	3 cm	
Size of Image	cm	
Erect or inverted image larger or smaller than object		

CHART

Then, on each sheet, calculate the image distance and image size. Record these data. How well do the calculated and diagrammed values compare?

RESOURCE PACKAGE 3-1.4

CUSTOMER SATISFACTION

Imagine that you have been promoted to Assistant Vice-President in charge of Store Security for Beiman Snarcus.

Several of the store's prominent customers have complained that the store security mirrors "bulge out" at them like eyes. They are not complaining about the mirrors' presence, but about their shape. Your boss, considering the Beiman Snarcus tradition of "customer satisfaction," is thinking about changing the shape of the mirrors; but before making a decision, she has assigned you the task of writing a report on the differences between "bulging out" (convex), "straight" (flat), and "bulging in" (concave) mirrors and the possible effects upon store security if the "bulging out" mirrors are replaced by either of the other two kinds.

When you have completed this report, show it to your real boss (your instructor) and await the decision.

RESOURCE PACKAGE 3-1.5

CURVED MIRROR USAGE

There are more purposes for which curved mirrors are used than there are for plane mirrors. List as many common uses of curved mirrors as you can think of and record whether the mirror is convex or concave. Also, make a list of occupations that utilize curved mirrors. (Should you not know where to find this information, ask your instructor to help you. He/she can suggest several references.)

RESOURCE PACKAGE 3-1.6

THE OLD-LIGHT-BULB-IN-THE-EMPTY-SOCKET TRICK!

Knowing the properties of curved mirrors, you can perform the following trick. A concave mirror is used to project a real image of a light bulb that is concealed upside down in a box (see Fig. 1 on page 72).

The image is formed over an empty light socket on top of the box. With the room properly darkened, the audience sees a real light socket and also the image of the concealed bulb. The illusion fools many into thinking that an actual light bulb is in the real, but empty, socket. The performer can even hit this light bulb image with a hammer; but, of course, the "bulb" will not shatter.

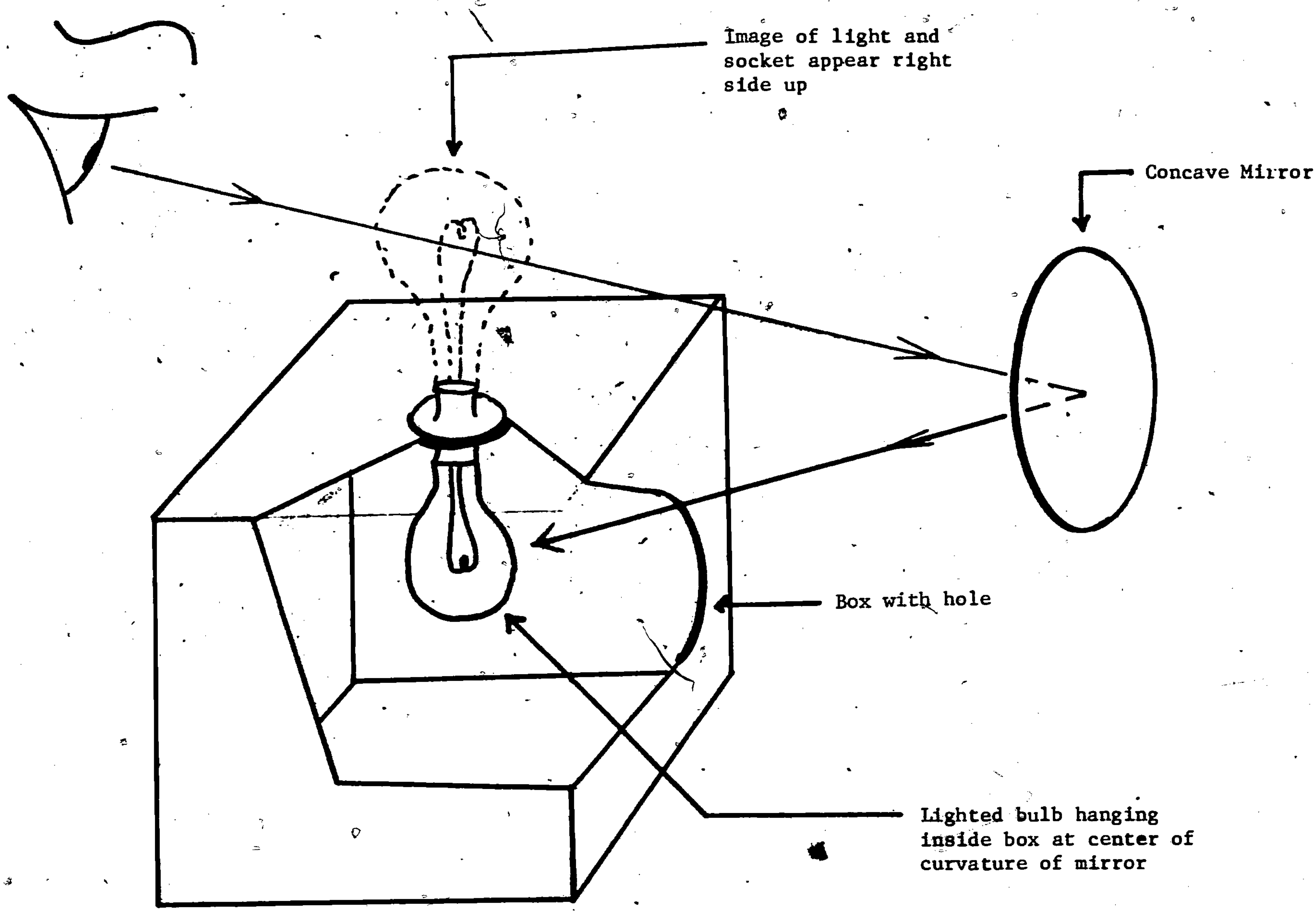
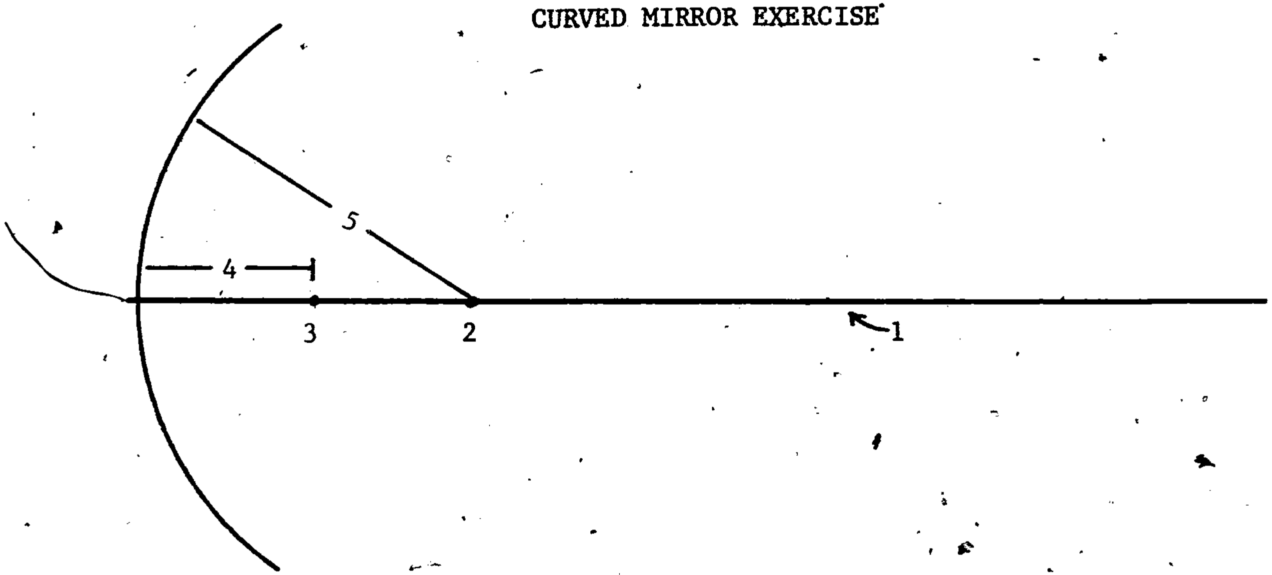


Fig. 1

THE OLD LIGHT-BULB-IN-THE-EMPTY-SOCKET TRICK

RESOURCE PACKAGE 3-2.1

CURVED MIRROR EXERCISE



1. Look at the diagram above. In your notebook, write down the identity of the numbered items in the diagram.

   1) ______________________

   2) ______________________

   3) ______________________

   4) ______________________

   5) ______________________

2. A converging mirror with a focal length of 30 cm is placed 40 cm from an object which is 10 cm high. In your notebook, calculate the location of the image (d_i), the height of the image (S_i), and further describe the image.

RESOURCE PACKAGE 3-2.2

ANSWERS TO EXERCISE

1.
   1) Principal axis
   2) Center of curvature
   3) Principal focus
   4) Focal length
   5) Radius of curvature

2. $f = 30$ cm

   $d_o = 40$ cm

   $S_o = 10$ cm

   $d_i = ?$

   $S_i = ?$

$$d_i = \frac{d_o \times f}{d_o - f} = \frac{40 \text{ cm} \times 30 \text{ cm}}{40 \text{ cm} - 30 \text{ cm}} = \frac{1{,}20\cancel{0} \text{ cm} \times \cancel{\text{cm}}}{1\cancel{0} \ \cancel{\text{cm}}}$$

$$d_i = 120 \text{ cm}$$

$$S_i = \frac{d_i \times S_o}{d_o} = \frac{120 \text{ cm} \times 10 \text{ cm}}{40 \text{ cm}}$$

$$\frac{1{,}20\cancel{0} \text{ cm} \times \cancel{\text{cm}}}{4\cancel{0} \ \cancel{\text{cm}}}$$

$$S_i = 30 \text{ cm}$$

Thus, the image is 120 cm from the mirror, is enlarged to a height of 30 cm, is inverted, and is real.

RESOURCE PACKAGE 5-1.1

REFRACTION I

Look at Figures 1 through 9. In your notebook, explain simply why the penny appears and then disappears. This phenomenon ("happening") is known as refraction.

Fig. 1

Fig. 2

Fig. 3

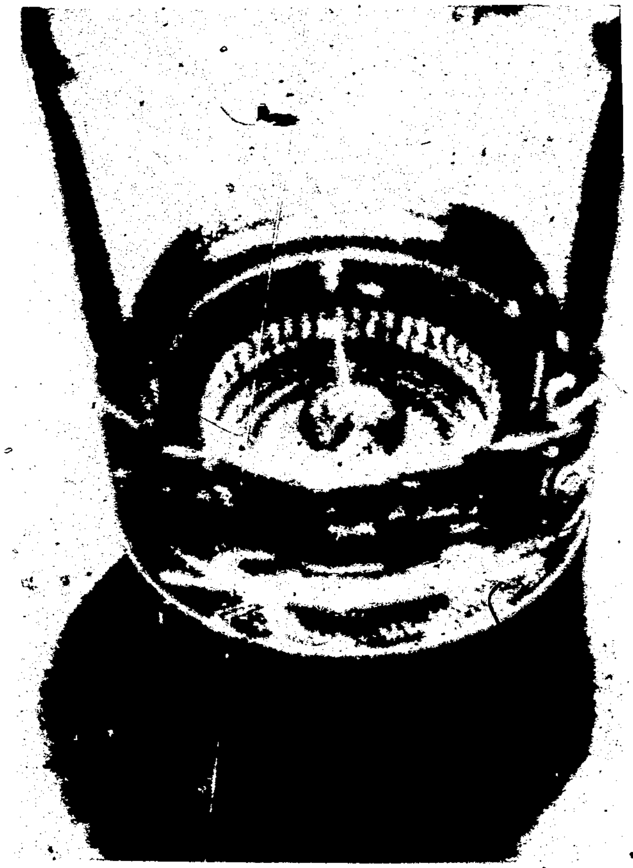


Fig. 4

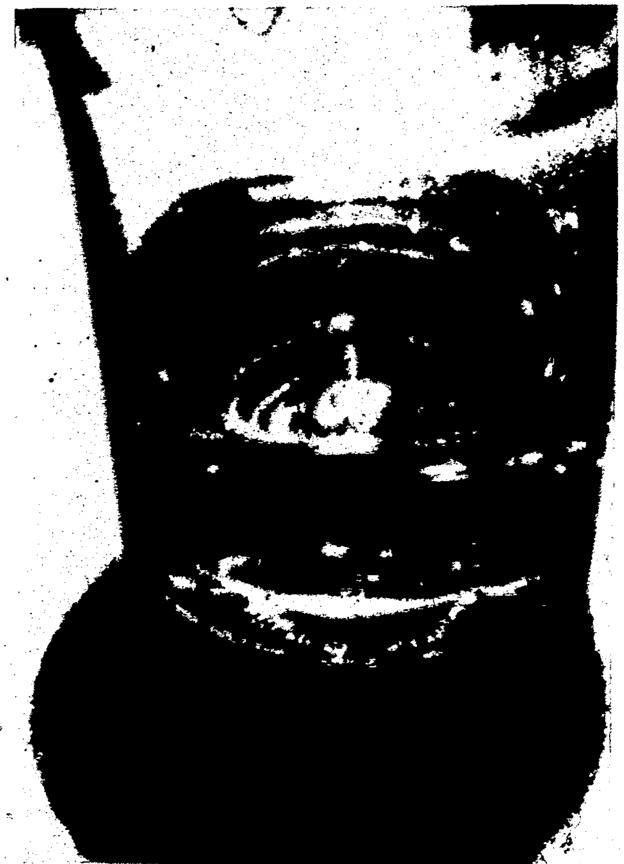


Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Read about refraction in a textbook. Consult your teacher about the recommended sections to read. (If you have Physics, A Basic Science, read pages 227-230.) Also, read about refraction in any three of the references listed below:

Compton's Encyclopedia

World Book Encyclopedia

Encyclopedia Britannica

Encyclopedia Americana

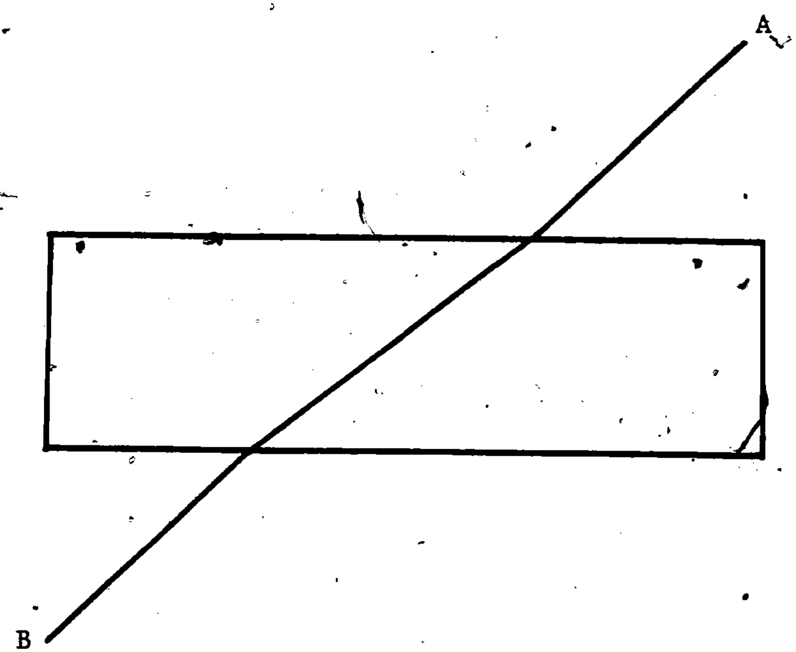
Encyclopedia of Science and Technology

RESOURCE PACKAGE 4-1.2

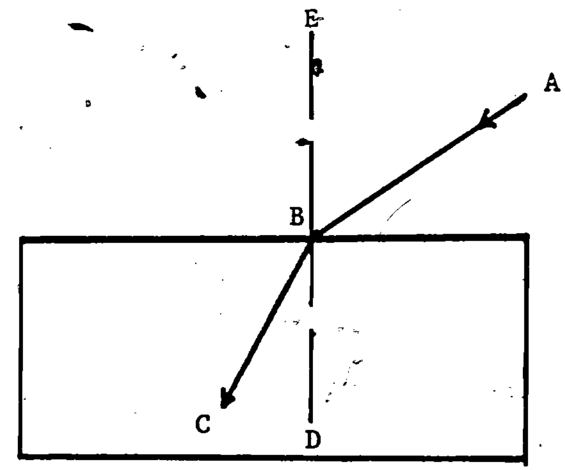
REFRACTION II

From your reading of Resource Package 4-1.1, you should be able to complete the following exercises. If you should have trouble, review your readings and/or perhaps consult your instructor. Write your responses in your notebook (please, NOT IN THIS BOOK).

1) The refraction of light is a (bending, bouncing) ________________ of light as it passes from one medium into another.



2) In the figure above, the direction of light is (A to B; B to A; impossible to determine from the data given). Select one of these as an answer.



3) Complete:

Line DE is the ____________________.

ABE is the angle of ______________ at B.

CBD is the angle of ______________ at B. Which angle should be the larger, ABE or CBD?

4) Light travels ____________ (faster, slower) as it travels into a denser medium. The ____________ (ratio, product) of the sines of the corresponding angles of incidence and refraction is called the refractive ________ (medium, index).

A general rule for refraction may be stated: "As light passes from one substance into another in which it travels slower, it is bent __________ (away from, toward) the normal. The refraction occurs (at the surface of, within) ______________ the denser substance."

5) Arrange the following in the order in which light travels the fastest:

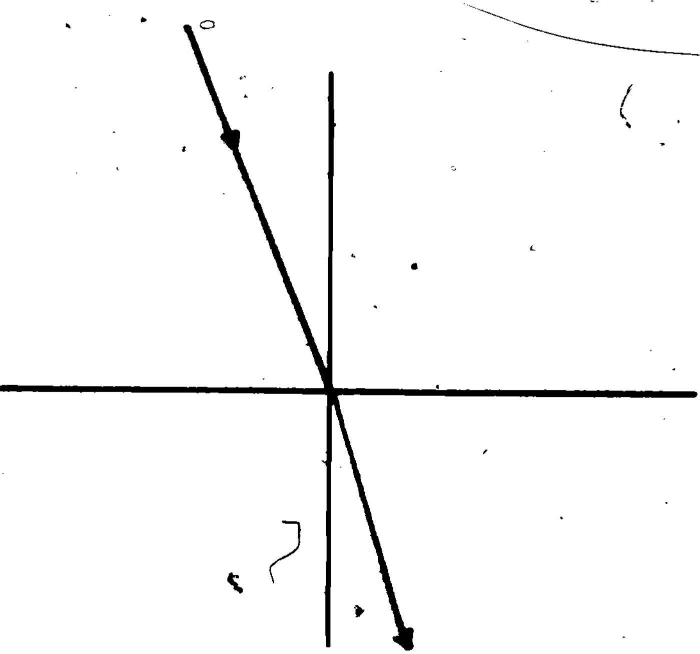
a) water
b) Lucite
c) diamond
d) gasoline
e) vacuum
f) ice
g) curved glass

6) Using a protractor, measure the angle of incidence and angle of refraction for each of the following drawings. List your measurements in tabular form in your notebook.

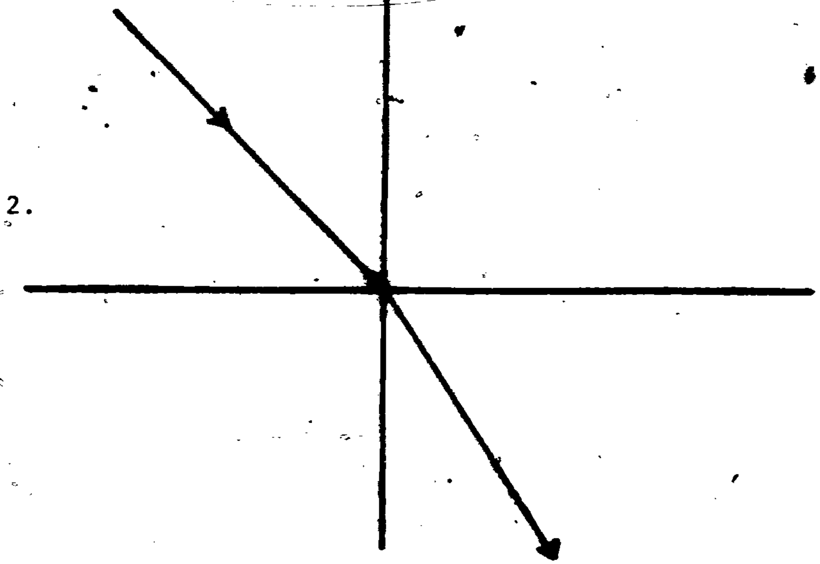
Data

Number of Drawing	Angle of Incidence	Angle of Reflection

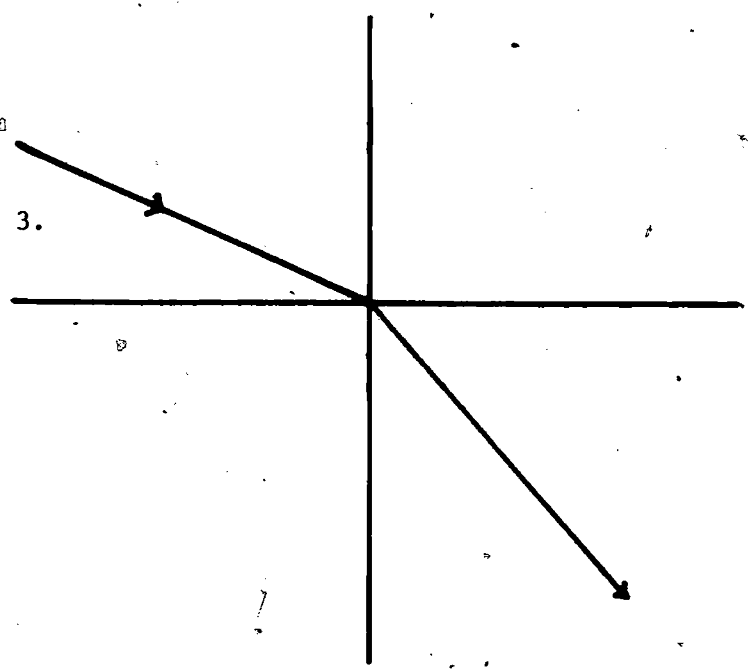
1.



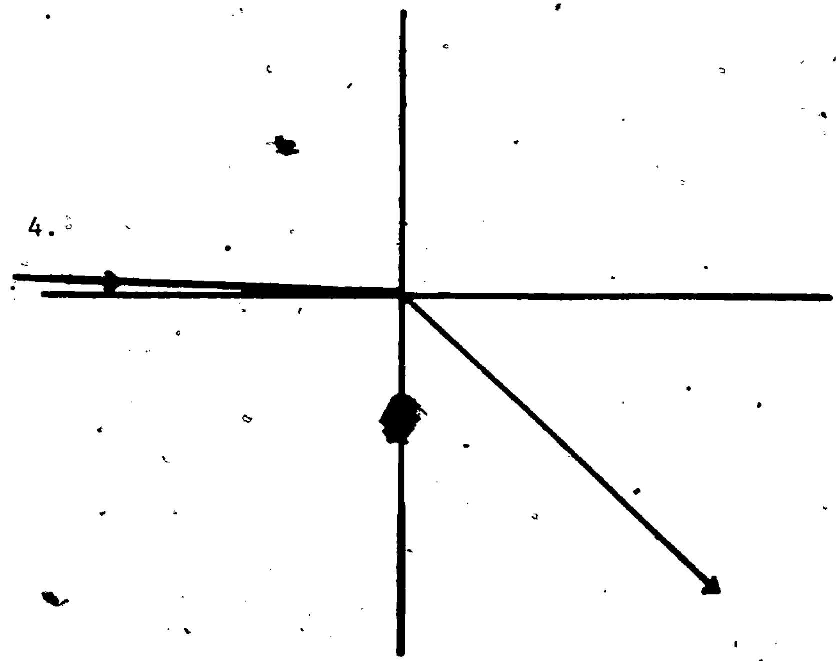
2.



3.



4.

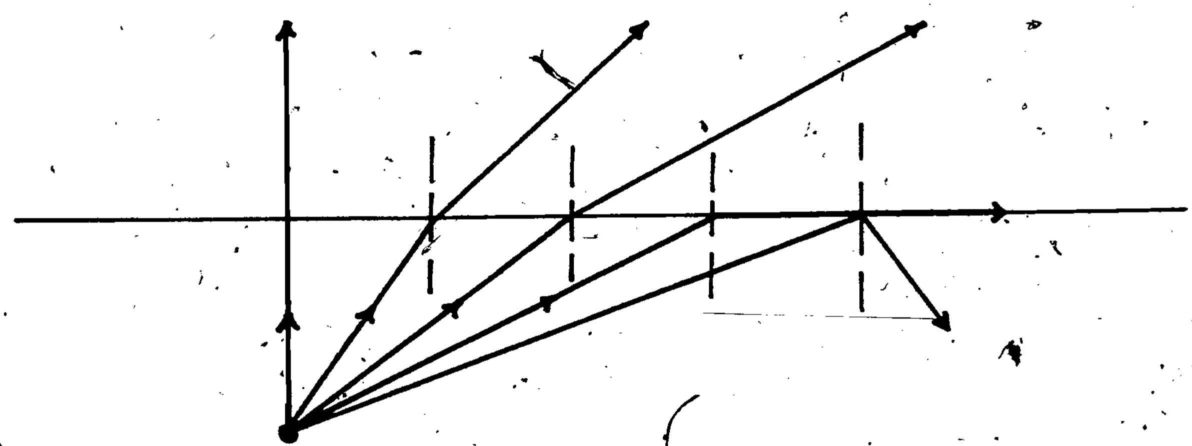


Using a trig. table, find the sine of the angle of incidence (sin i) and sine of the angle of reflection (sin r). List in tabular form and compute the ratio, sin i/sin r. Compute the average of this ratio.

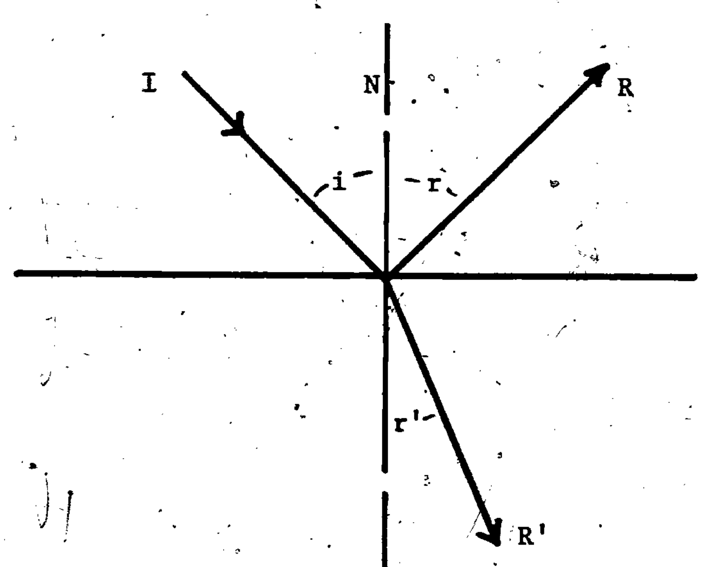
Drawing	Sin i	Sin r	Sin i/Sin r

Average ______________

7) In the diagram below, which angle would be considered the critical angle? What is the critical angle for a water-air surface? A glass-air surface?



8) Name each of the following:



a) I ______________________

b) N ______________________

c) R ______________________

d) R' ______________________

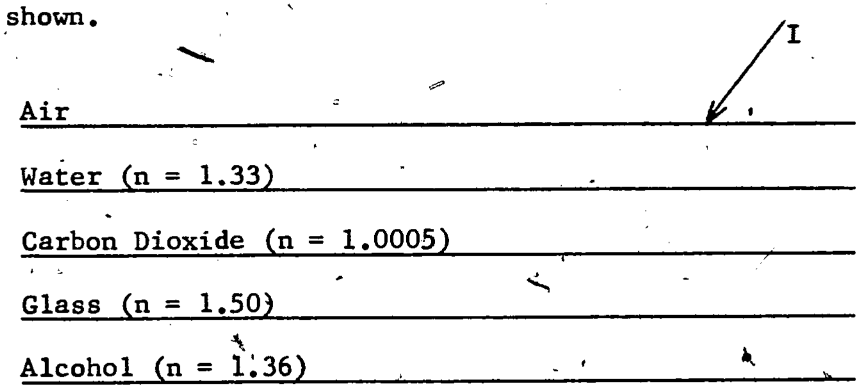
e) i ______________________

f) r ______________________

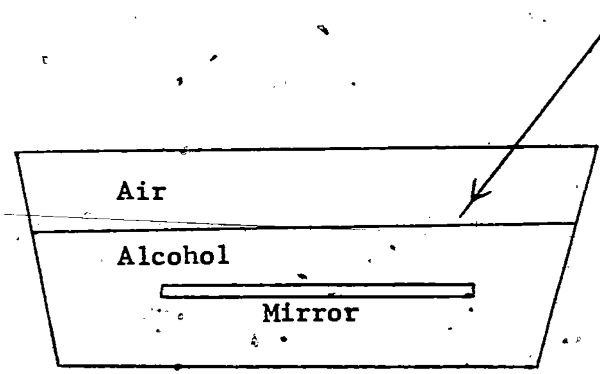
g) r' ______________________

9) What two people can be credited with discovering the laws of refraction?

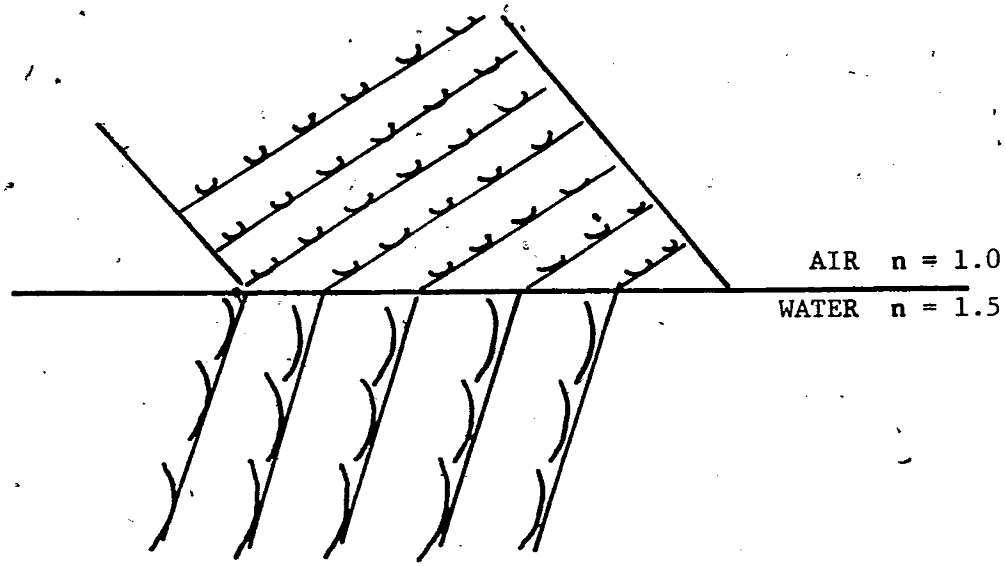
10) Draw your own diagram and complete the path of the incident ray, I, across the various transparent layers shown.



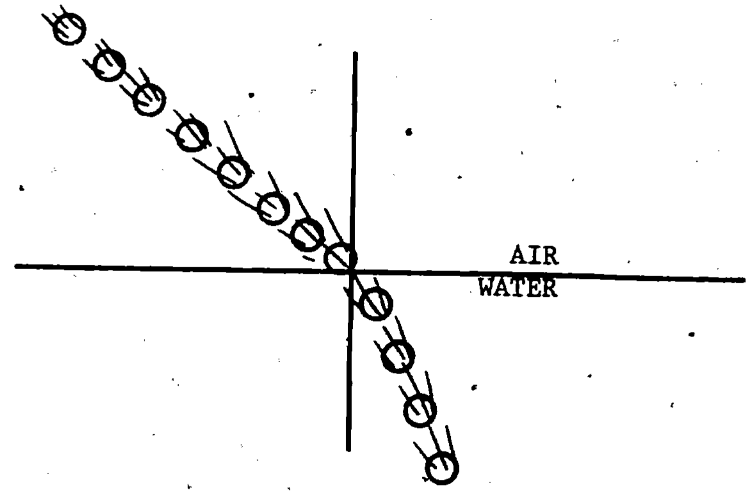
11) Draw your own diagram and complete the path of the ray of light indicated in the drawing. The ray passes into alcohol, is reflected from a plane mirror, and finally emerges into air again.



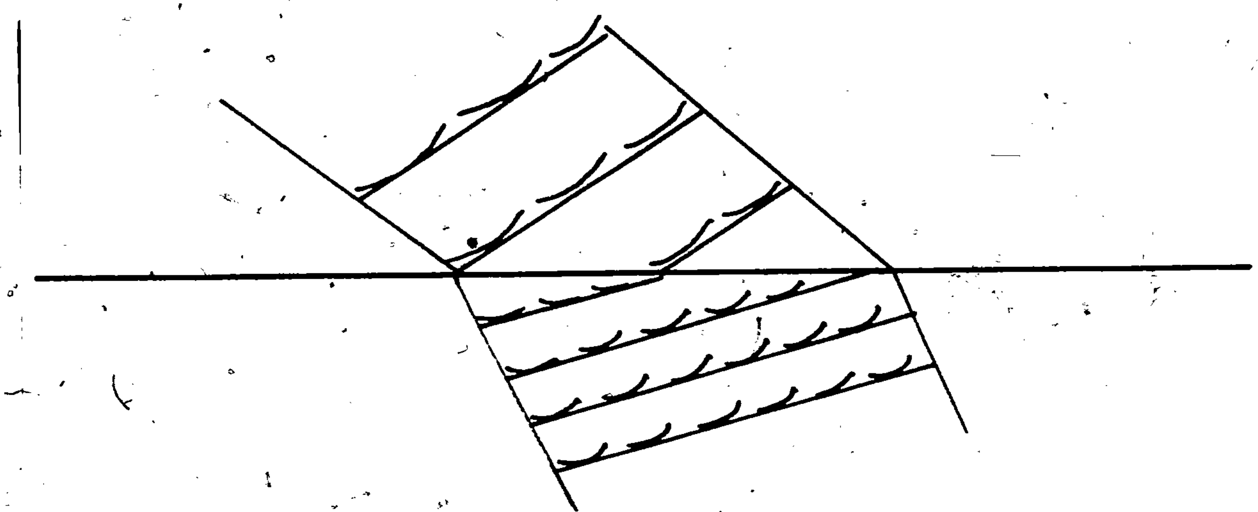
12) What is incorrect about the drawing below?



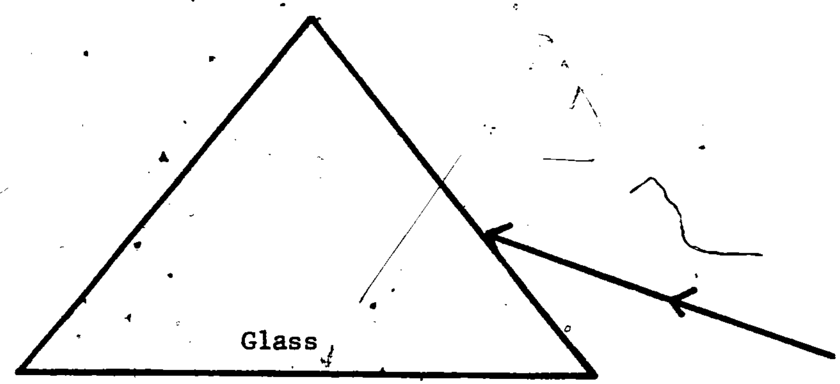
13) What man would this diagram be associated with?



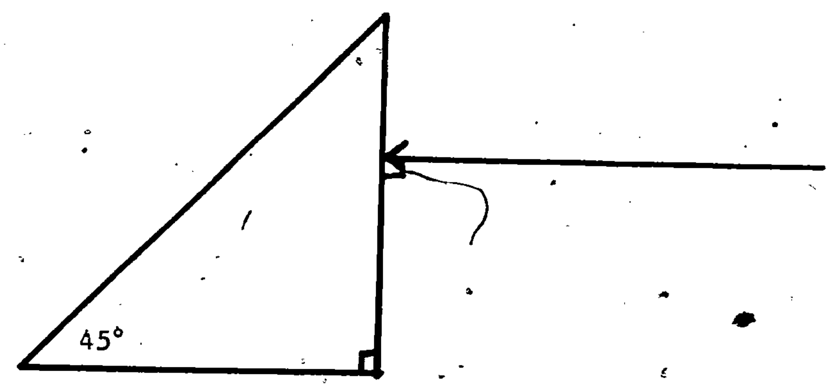
14) What man would this diagram be associated with?



15) Complete the path of the rays shown. Draw and label all normals and rays at each surface.



16) Complete the path of the rays shown. Draw and label all normals and calculate all angles.



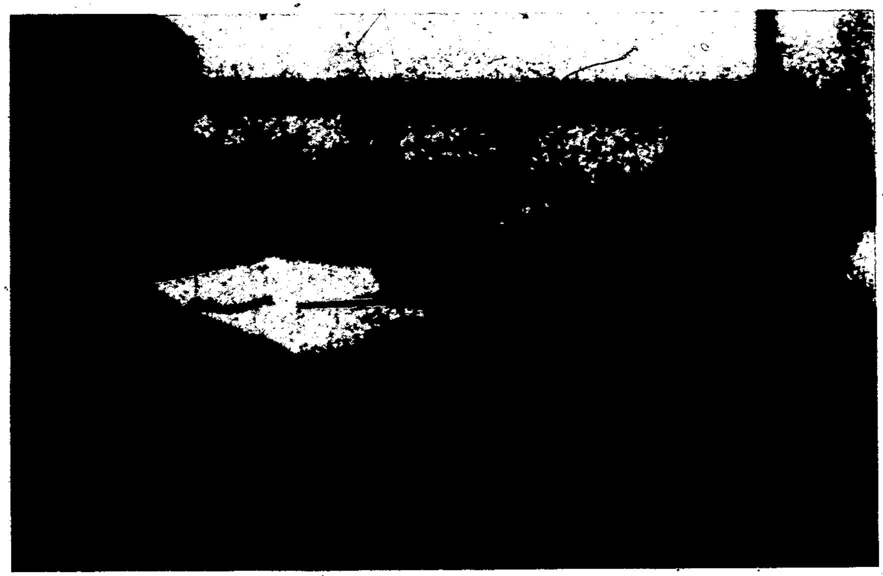
17) The index of refraction can be expressed as the ratio of speed of light in a vacuum (c) and the speed of light in a medium (v). The index of refraction of a diamond is 2.42. The speed of light in it is ______________ m/sec.

RESOURCE PACKAGE 4-1.3

INDEX OF REFRACTION

You will need:

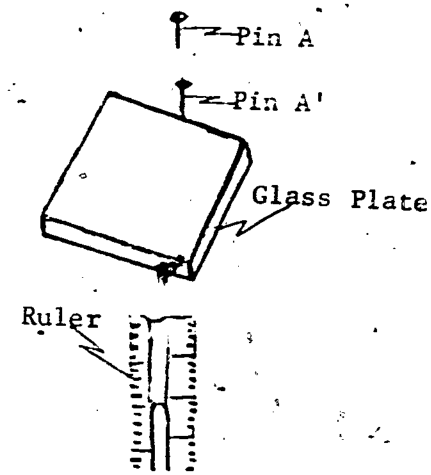
- Rectangular glass plate
- Wooden drawing board
- Drawing compass
- Ruler
- Straight edge



Place a rectangular glass plate on a line drawn on a sheet of paper. Look at the line through the glass; view the line from different angles. Describe the appearance of the line as the view angle is changed.

Place the glass plate on a different sheet of paper and draw a sharp pencil line around the glass. Place two pins back of the glass but not in a line perpendicular to the edge of the glass. With a ruler in front of the glass plate, sight along the edge of the ruler until the edge is directly in line with the two pins. Draw a pencil line along the edge of the ruler (see picture above). After

removing the glass plate, extend this line until it meets the line indicating the edge of the glass nearest you (see sketch on page 93). Mark this intersection C. Remove the two pins, marking their locations A and A' (see sketch at right). Draw a line through these two points until it also meets the edge of the glass nearest them. Mark this intersection B. Draw a line from B to C and construct a perpendicular at B. Extend this perpendicular above and below point B, and label it OP. Now, using B as the center, construct arcs through E and H. Label the points G and H. From these points, construct FG and EH perpendicular to OP (see sketch on page 93).

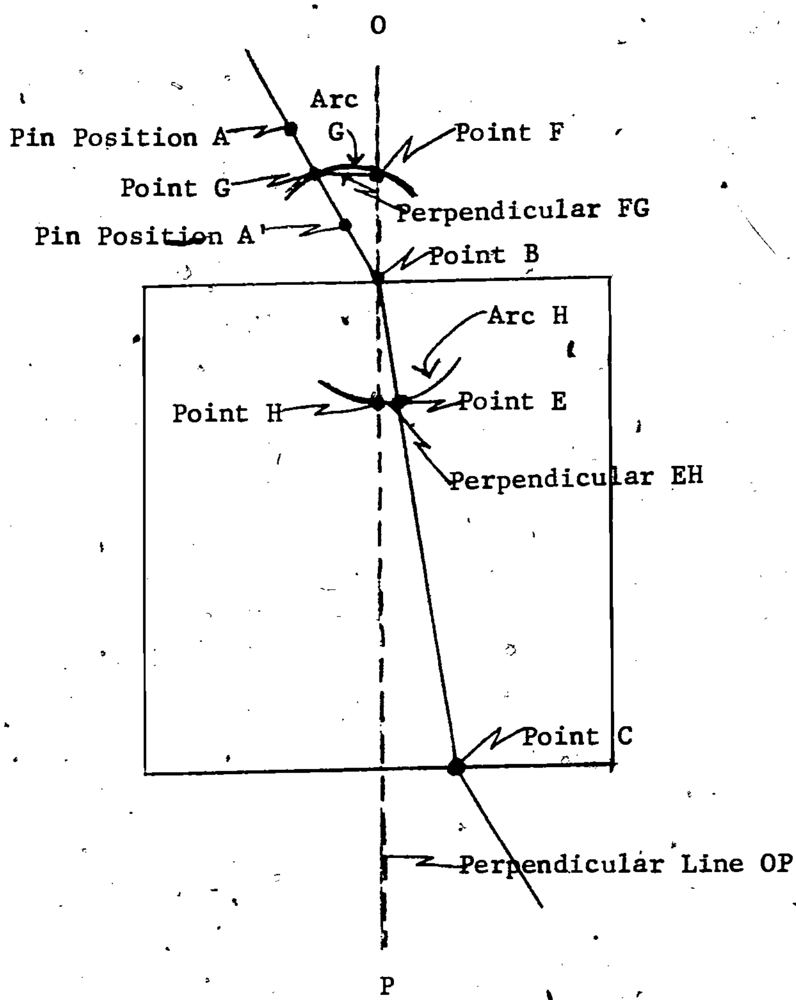


You should now have two <u>congruent</u>* triangles--BFG and BHE.

$$\text{Index of refraction} = \frac{\text{sine of angle of incidence } (\sin i)}{\text{sine of angle of refraction } (\sin r)}$$

---

* Congruent triangles are triangles which, if rotated properly, can be theoretically moved and placed one on top of the other, for a precise matching.


O
Arc G
Pin Position A
Point F
Point G
Perpendicular FG
Pin Position A'
Point B
Arc H
Point H
Point E
Perpendicular EH
Point C
Perpendicular Line OP
P

Label the angle of incidence, "i," and the angle of refraction, "r."

$$\text{Sin } i = \frac{FG}{BG}$$

$$\text{Sin } r = \frac{EH}{BH}$$

Thus, Index of Refraction =

$$\frac{FG/BG}{EH/BH}$$

$$= \frac{FG}{\cancel{BG}} \times \frac{\cancel{BH}}{EH}$$

Since BG and BH are equal (hypotenuse of congruent triangles), the index of refraction =

$$\frac{FG}{EH}$$

Now, measure FG and EH carefully. (Try to read as close to tenths of a millimeter as possible). Record the data in your notebook in a chart similar to the one on page 95. Then compute the index of refraction of the glass and compare it to the actual index of refraction (the actual index can be found in a table; crown glass is 1.50; water is 1.33, etc.)

Data

Length of FG	______ mm
Length of EH	______ mm
Index of refraction calculated	______ mm
Actual index of refraction	______ mm

Last, answer these questions in your notebook:

Questions

1) How many times was the light ray bent as it passed through the glass?

2) At what point(s) were the light ray's bent?

3) Is there a similarity between the angle at which the light enters the glass and the angle at which light leaves the glass?

4) Is light bent toward or away from the perpendicular as it passes from air into glass? From glass into air?

RESOURCE PACKAGE 4-1.4

ATMOSPHERIC REFRACTION

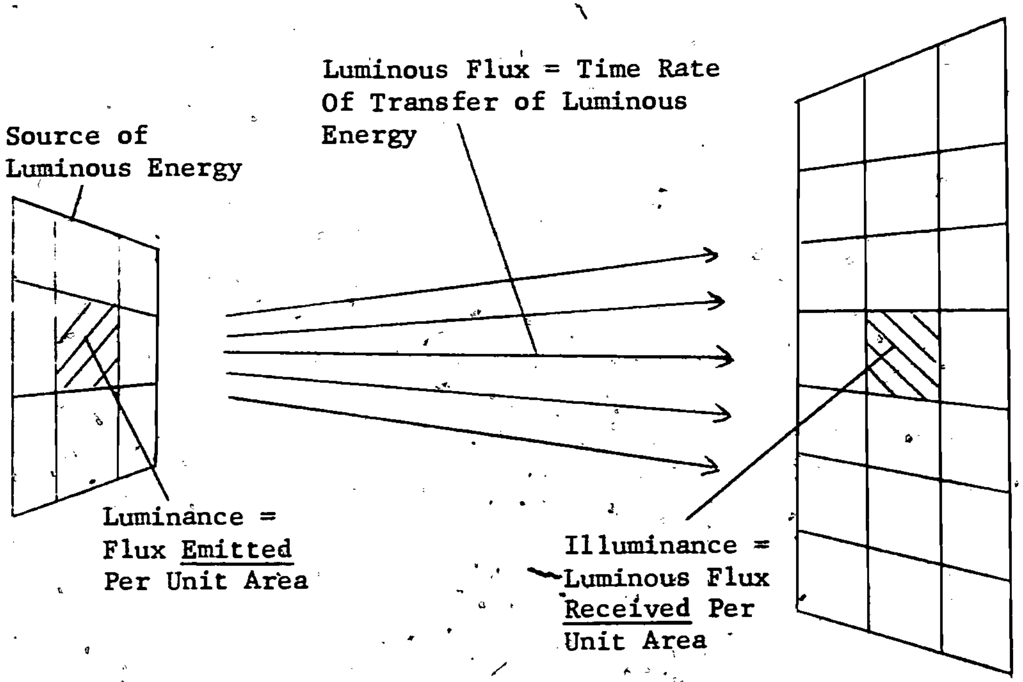
At sunrise or sunset the position of the sun's disc appears above the actual location of the sun by about 0.5°. The sun's spherical shape also appears flattened. From your study of the refraction of light as it passes through different media, can you explain the phenomena? Use diagrams, and answer in your notebook.

An equally interesting study is to determine whether the moon is really larger as it rises on the horizon (it appears to be larger) than when it is directly overhead. Photographs of the moon when it is overhead show that the two images have identical size and shape. This phenomenon of an enlarged moon is commonly called the "moon illusion" and is partially accounted for by atmospheric refraction.

RESOURCE PACKAGE 5-1.1

ILLUMINATION

The energy produced by a luminous source may be regarded in the same manner as any other form of energy and therefore is expressible in the energy units, <u>ergs</u> or <u>joules</u>. The rate of transfer of luminous energy is called <u>luminous flux</u>, which is expressible as ergs/sec or joules/sec (1 joule/sec = 1 watt). A <u>source</u> of luminous energy <u>emits</u> a certain amount of luminous flux per unit area, called <u>luminance</u>. The luminous flux received by a unit area of an illuminated surface is called <u>illuminance</u>. Both luminance and illuminance are expressible in watts per square centimeter or watts per square meter, although other units are sometimes employed in specifying these quantities.



A unit of luminous flux is the <u>lumen</u>. Let us first consider luminous intensity, and then return to the lumen. For many years luminous intensity was the quantity that served as the basis for all light measurement. The standard for intensity was the standard candle. The standard candle was a candle of sperm wax burning at a rate of 120 grains per hour. We can think of the candle as the center of a unit sphere, and the total flux emitted by the standard candle was 12.56 lumen.

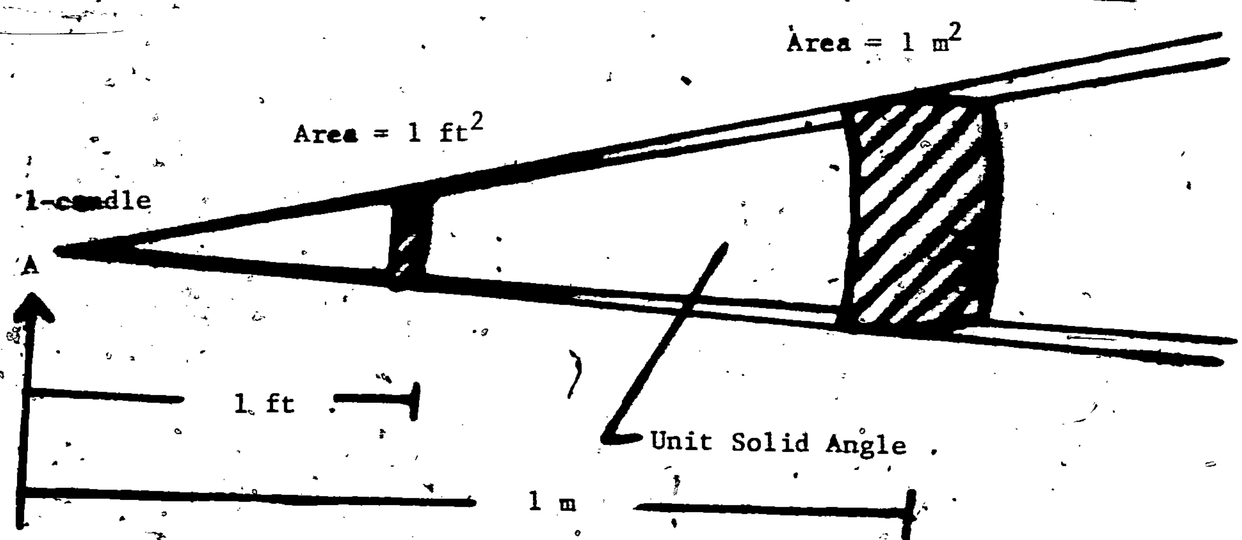
The standard candle could not easily be precisely reproduced and was soon replaced by a group of carbon filament lamps operated at a carefully prescribed voltage. Such carbon lamps are still maintained at the National Bureau of Standards and constitute primary standards for intensity. A more modern standard candle slightly smaller than the old has been adopted for international use. This new standard candle is based on the luminous intensity supplied by the surface of a theoretically perfect absorber and perfect emitter of radiation at the temperature of freezing platinum (2046° K). The new <u>international candle</u> is defined as 1/60 of the luminous intensity of a square centimeter supplied by this perfect body.

Because luminous flux is the time rate of transfer of luminous energy, if you multiply this rate by the period of time over which it is maintained, the result is the total luminous energy transferred (lumen-seconds). If the average luminous flux of a lamp is 33 lumen and the time for which the light is turned on is 30 minutes, then the total energy emitted will be 33 lumen x 30 minutes x 60 sec/min, or 55,400 lumen-seconds.

Make a chart similar to the one below. In your notebook, calculate the luminous energy transfer for each of the following light sources and record these on the chart:

LIGHT SOURCE (watt)	AVERAGE LIGHT OUTPUT (lumen)	TIME (min)	LUMINOUS ENERGY (lm-sec)
15	120	30	
25	220	30	
40	440	30	
60	855	30	
75	1170	30	
100	1710	30	

Illuminance is the next quantity to be considered. Illuminance is the luminous flux striking a unit area of the surface that is being illuminated. The units of illuminance are lumens/meter^2. Illuminance can be expressed in the formula, $E = \frac{F}{A}$, where F is the luminous flux delivered to a surface area, A. Thus, a flux of 50 lumens distributed over an area of 5 meter^2 will produce an illuminance of $\frac{50 \text{ lumens}}{5 \text{ meter}^2}$, or 10 lm/m^2.



The meaning of illuminance can be seen in the drawing above. A is a point source of light of 1-candle intensity producing a flux of 1 lumen per unit solid angle*. If a sphere is 1 foot in radius and is drawn with the source as the center for a unit solid angle, the area cut out of the spherical surface will be 1 ft^2. Likewise, in a sphere of 1 meter radius drawn about A, a unit solid angle will intercept an area of 1 m^2. The illuminance in the first case is therefore 1 lm/ft^2, and in the second, 1 lm/m^2. Does illuminance vary with the intensity of the light source? Make a chart like the one below in your notebook. Use the formula for illuminance, $E = \frac{F}{A}$, and calculate the E values necessary to complete the chart.

---

* It turns out, from solid (spherical) geometry that there are "4π solid angles" in every spheroid.

F (lm)	A (ft^2)	E (lm/ft^2)
10	1	
20	1	
30	1	
40	1	

Your calculations should convince you that illuminance varies directly with the intensity of the source, provided the distance between the source and the surface remain constant.

To determine the effect of distance on illuminance, assume that a source emits energy through 4π solid angles (spherically, in all directions) and that the luminous intensity of the source is held constant. Then, in your notebook, calculate E and complete the following chart:

F (lm)	Distance From Source (ft)	A (ft^2)	E (lm/ft^2)
10	1		
10	2		
10	3		
10	4		

You should see from your calculations that the illumination varies inversely with the square of the distance from the point source, provided that the intensity of the source is kept the same.

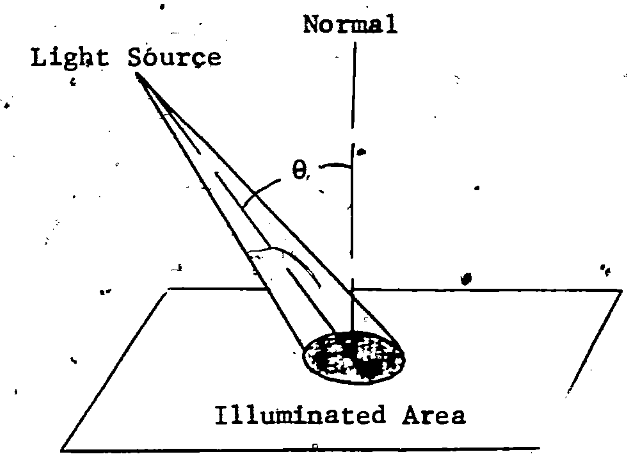
The relationship between illuminance E, luminous intensity I, and the distance between the source and the surface r can now be expressed as $E = \frac{I}{r^2}$, where I is given in candles, r in feet, and E in lumens, ft^2 (loosely called foot-candles).

If you don't understand enough trigonometry, ask your teacher to explain this next section or get permission to skip it.

If the luminous flux strikes at an angle θ between the normal to the surface and the direction of the flux, the illuminance received by the surface is given by

$$E = \frac{I}{r^2} \cos \theta.$$

This is a more general formula than the restricted, $E = \frac{I}{r^2}$; for if the direction of light is normal to the surface, then $\theta = 0^o$ and the $\cos \theta = 1$.



PROBLEM 1: What is the illuminance produced by a lamp source of intensity 1710 lumen and 5 feet from the surface? Assume normal incidence.

$I = 1710$ lumen

$r = 5$ feet

$\theta = 0^o$

$r^2 = 25\ ft^2$

Since the angle is zero, $\cos \theta = 1$; therefore, $E = \frac{I}{r^2}$ is multiplied by one. So we can use

$$E = \frac{I}{r^2}$$

$$E = \frac{1,710 \text{ lumen}}{25 \text{ ft}^2}$$

$$E = 68 \text{ lm/ft}^2$$

PROBLEM 2: Light originating from a spotlight of 10,000 lumen intensity reaches a stage surface 50 feet away at an angle of 60^o with the normal. What is the illuminance on the stage surface?

$I = 10,000$ lumens

$r = 50$ feet

$\theta = 60^o$

$\cos \theta = 0.5$

$r^2 = 2,500 \text{ ft}^2$

$$E = \frac{I}{r^2} \cos \theta$$

$$= \frac{10,000 \text{ lumen}}{2,500 \text{ ft}^2} \times 0.5$$

$$= 2 \text{ lm/ft}^2$$

RESOURCE PACKAGE 5-1.2

PHOTOMETRY

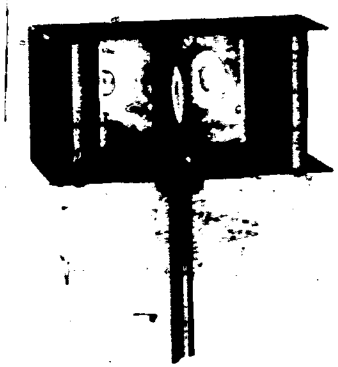
A source of unknown intensity can be calibrated with a source of known intensity. This is accomplished in the Bunsen photometer by viewing simultaneously both sides of a transparent "oil spot" illuminated by the two sources placed at opposite ends of the apparatus (see Figure 1). The position of the photometer head on the meter stick is adjusted until the oil spot appears illuminated on both sides. When this condition of balance is reached, the following equation can be used to determine the intensity of the unknown source:

$$\frac{I_1}{d_1^2} = \frac{I_2}{d_2^2}$$

where d_1 and d_2 are the distances from I_1 and I_2 to the photometer head.

The equation may also be stated as

$$\frac{I_1}{I_2} = \frac{d_1^2}{d_2^2}.$$

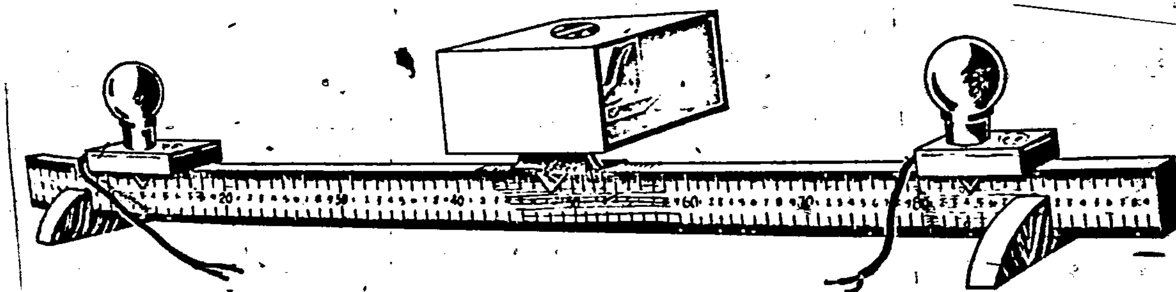


BUNSEN PHOTOMETER
Fig. 1

INVESTIGATING LIGHT BULB INTENSITY:

Is the light output printed on light packages correct? To find out, you will need the following equipment:

-- Bunsen photometer
-- standard intensity lamp*
-- 40-, 60-, and 100-watt lamps
-- meter stick
-- 2 lamp sockets
-- 2 optical bench supports



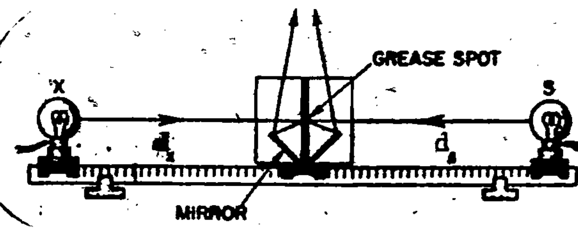
INVESTIGATING LIGHT BULB INTENSITY
Fig. 2

Darken the room (or arrange the photometer setup) so that any stray light illuminates the grease spot equally on both sides. Place the standard intensity lamp* in the socket at the right and place each of the "unknown" lamps, in succession, in the socket at the left. Connect the lamps to a source of voltage (in precise experiments, voltage should be carefully controlled). Slide the photometer head

----

* If you do not have a standard intensity lamp, choose a lamp as "standard" and investigate the others relative to it.

along the meter stick until the condition of "balanced" illumination is obtained. In your notebook record all data in a chart such as the one below; also show computations.



USING THE PHOTOMETER
Fig. 3

Calculate the intensity of the "unknown" with the formula,

$$I_x = \frac{I_s \times r_x^2}{r_s^2}$$

Table A

Lamp being tested	I_s (intensity of standard)	r_s (distance of standard from photometer	r_x (distance of unknown from photometer)	I_x (intensity of unknown)	Number of lumens printed on package	Difference
40-watt	..... lm	..... cm	..... cm	..... lm	..... lm	..... lm
60-watt	..... lm	..... cm	..... cm	..... lm	..... lm	..... lm
100-watt	..... lm	..... cm	..... cm	..... lm	..... lm	..... lm

In technical applications, so-called <u>direct systems</u> of illumination employ fixtures which send 90 percent of the light output directly downward to the working area. So-called <u>indirect systems</u> deflect from 90 to 100 percent of their light output upward, to be subsequently reflected downward onto the work area (usually reflected downward by the ceiling, which becomes a secondary source of light). A so-called

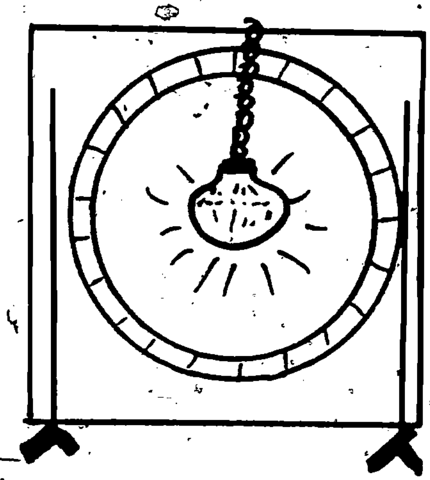
semi-direct system of illumination is one in which 60 percent or more of the light is transmitted downward, and the remainder upward as in the indirect system.

INVESTIGATING LIGHT DISTRIBUTIONS:

A graph of the intensity with which light from a system is distributed can easily be made from direct observations. You will need:

-- Illumination meter
-- Polar coordinate graph paper
-- Protractor
-- Large sheet of cardboard (about 3 ft x 3 ft)

Draw a 15-inch radius circle on the cardboard; then draw a 12-inch radius circle, using the same center. After you have marked increments of 10^{o} on the band formed by the two circles, cut out the inside of the 12-inch circle. Support the cardboard with two ringstands (see Figure 4). The light system to be graphed should be placed at the center of the circles. Readings are then made with the illumination meter at the different increments. Readings should take place in a darkened room to avoid illumination from other systems. Your graphs should indicate where the maximum intensity of the system is located. You should also find some interesting designs on your graphs. In your polar coordinate paper, plot intensity vs. angle, and paste or tape the graphs into your notebook.



INVESTIGATING LIGHT
DISTRIBUTION

RESOURCE PACKAGE 6-1.1

REFRACTIVE FIBERS

It has been known for years that a pipe of highly polished silver or aluminum can transmit light along its ~~interior~~ even if it is curved. Light, after entering one end of such a tube, is reflected back and forth inside the tube until it comes out of the opposite end. This is not a very efficient piping operation because there is a loss of light energy each time the light is reflected; and in a pipe having a length many times its diameter, many reflections take place and a large loss of light energy occurs.

One way to bring about an extended series of reflections without loss of much light energy is by having the reflections take place at a boundary between a dense medium (such as glass) and a rare medium (such as air) such that the light is bent at the critical angle (or greater angle), thus maintaining a minimum loss of light. One of the earliest means of transmitting light by tube refraction was the use of a lucite rod (see picture at right); but glass is now the preferred material for light pipes, wherever flexibility and cost are not important factors.

Light Pipe

While a single glass or acrylic rod will transmit light energy well, it will not convey an image except under special conditions. If you look at a printed page, you see it because the light reaches your eyes reflected from different areas on the page and with different degrees of intensity. Therefore, there will be more light in certain areas and less in other areas, so that a definite pattern occurs.

If the light waves from this same printed page were passed through a light pipe with a half-inch diameter, they would follow many different paths as they traveled through the pipe. Then, as the rays from all areas of the page left the light tube, the image would normally be so mixed as to be unrecognizable.

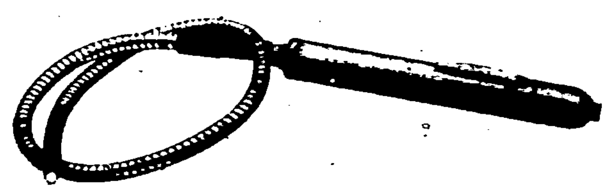
If you decrease the size of the pipes (to something like a coarse thread size) and group the pipes into bundles, then the image will be divided into a number of small areas. The image of each small area will be conveyed by a single fiber to a corresponding point at the other end of the bundle. Now we have the advantage of flexibility, plus the advantage of being able to reproduce an image. Such an arrangement is termed a <u>fiberscope</u> and is the basis of the science of <u>fiber optics</u>. A fiberscope enables a person to transmit an image around corners; for example, a surgeon can see inside a person's heart via the artery.

The idea of an optical pipe has been around for the last century, but many difficulties prevented its construction. One of the biggest drawbacks was that if simple fibers were in contact, light would leak from one fiber to another, causing a distortion of the image. Also, the surface of the fibers would become scratched as they touched, causing a loss of light energy at the scratches.

The problem was solved in the '50's by creating a fiber within a fiber, both transparent. The inner fiber has a high index of refraction, while the outer one has a low refractive index; and total

internal refraction takes place at the interface between the two fibers. This arrangement produces practically no light leakage and no loss due to surface abrasions. Generally, the flexible fiber bundles are enclosed with sheaths of metal or plastic to further protect them.

It is important that the position of the fibers at both ends be the same for proper image formation. This arrangement is not necessary elsewhere within the fiberscope. On the other hand, if it is only necessary to transmit light and not an image, the bundle ends can have any relationship. Such a bundle is called a "flexible light guide." Fiber bundles arranged at random are frequently called <u>incoherent</u> bundles, and those that are arranged to produce an image are called <u>coherent</u> bundles.



"Flexible Light Beam"

Total Internal Reflection in Fine Glass Fibers

There are many applications for fiber optic products. They can be used to provide illumination in surgery and in instrument panels. They can also be used to detect fires in out-of-the-way places. Fiberscopes can be used to see inside a stomach (a <u>gastroscope</u>). A miniature probe in the shape of a hypodermic needle has been developed to view muscle fibers, skin tissue, and blood cells. In

industry, fiberscopes serve as instruments to inspect or to control operations in hard-to-get-at places. For example, fiberscopes are used to examine turbine blades, boiler tubes, and various parts of nuclear reactors for flaws and cracks.

RESOURCE PACKAGE 6-1.2

FIBER LIGHT

INVESTIGATING FIBER LIGHT:

You will need:

- -- several coherent and non-coherent fiber bundles of the same length and diameter
- -- battery flashlight
- -- high-intensity lamp
- -- transparent color wheel, mounted for hand rotation
- -- ring stand and clamps
- -- double convex lens
- -- rubber bands

Join the light-receiving end of a number of non-coherent fiber bundles into a circle by means of a rubber band. Then arrange the light-exiting end to form a pattern such as the letter, "L." Point the light-receiving end toward a high-intensity lamp and check to see if an illuminated letter "L" becomes visible at the opposite end. In your notebook, sketch a diagram of the optical arrangement.

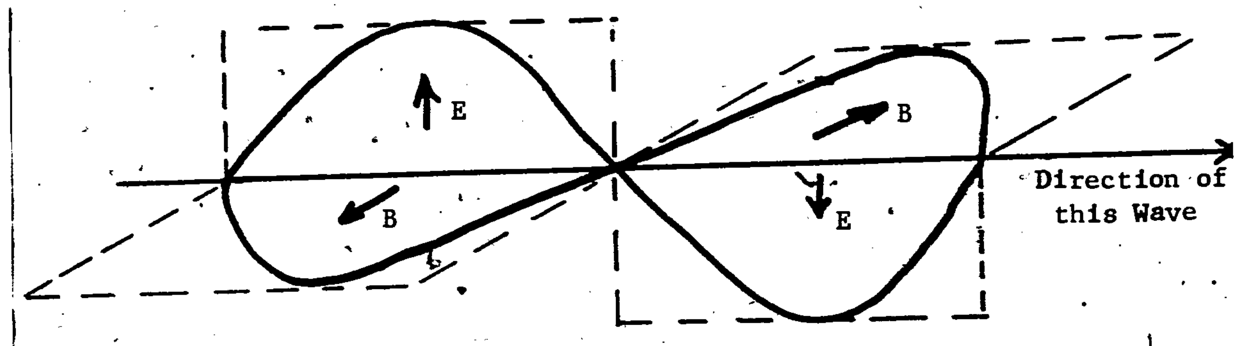
Now, place a color wheel between the source light and the light-receiving end. Rotate the wheel slowly and describe the images at the other end. Record why it was not necessary to employ coherent fiber bundles for this. Twist a non-coherent fiber bundle into a wide U-shaped curve. Hold one end of the "U" close to your eye and direct a beam of light from a flashlight toward the other end. In your notebook, record your observations.

Use a high-intensity light to illuminate a printed page. By means of a lens, focus the image of the page on the face of a coherent fiber bundle twisted in the form of a semi-circle. (Be sure to reduce the size of the image to a size small enough to cover the face.) Examine the exit end carefully and see if you can detect a clearly defined image. Record whether or not the image is continuous or is composed of spots of light. Make a sketch of your image and of the optical arrangement in this investigation.

RESOURCE PACKAGE 7-1.1

POLARIZED LIGHT I

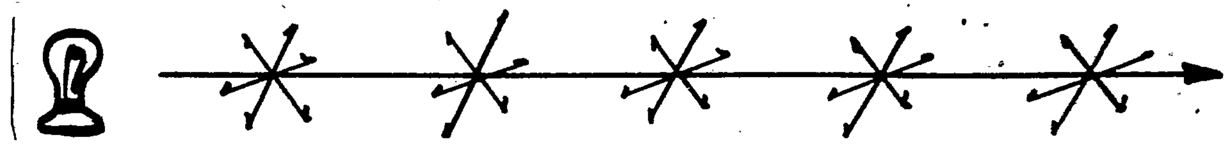
Light is considered a transverse wave composed of electric and magnetic fields oscillating at right angles to each other and at right angles to their direction of travel (propagation). Unpolarized light consists of waves whose electric and magnetic planes are randomly oriented; whereas, for polarized light, these planes have a fixed orientation in space.



Plane of Magnetic Field = B
Plane of Electric Field = E

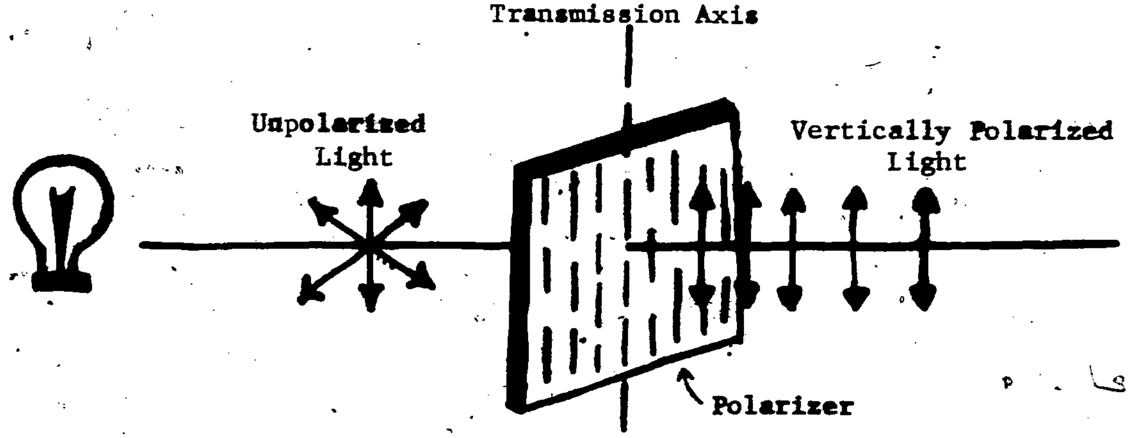
ELECTROMAGNETIC WAVE
Fig. 1

Figure 1 shows a polarized light wave moving to the reader's right. The E and B fields are up and down (electric) and in and out (magnetic), respectively. Because E and B fields always oscillate in their respective planes, this wave is polarized.



NON-POLARIZED E-WAVE
Fig. 2

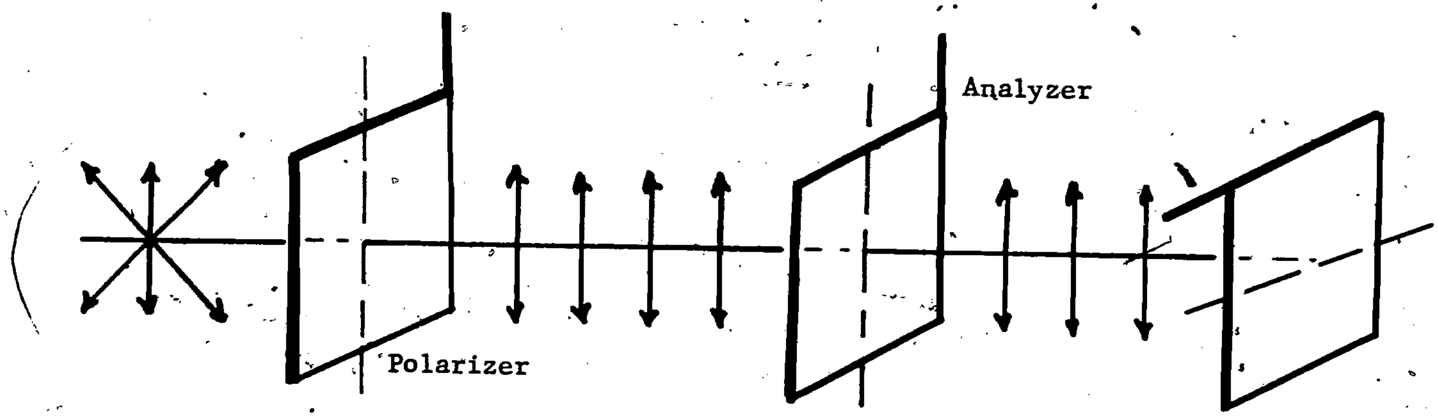
Figure 2 shows non-polarized vibrations of the electric component only. We know that the magnetic component simply stays at right angles always to the electric component; so if we know what one is doing, we know what the other is doing. Notice that the electric component is not restricted to any plane of vibration. If the vibration of the electric component is restricted to only one direction, the resulting light is plane-polarized (see Figure 3, below).



POLARIZING LIGHT
Fig. 3

Plane-polarization shows a definite orientation of the electric field that it lacked before. This is accomplished by placing some type of polarizing device in the path of unpolarized light. This polarizing device requires a definite alignment of the light components it passes.

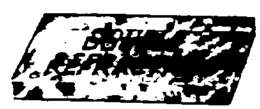
If a second polarizing device is placed with its transmission axis parallel to the first, the light polarized by the first will continue through the second. But if the second device is rotated 90° so that its transmission axis is at right angles to that of the first, a condition can be reached for which no light can pass (see Figure 4, below). The first device is referred to as the polarizer; and the second, as the analyzer.



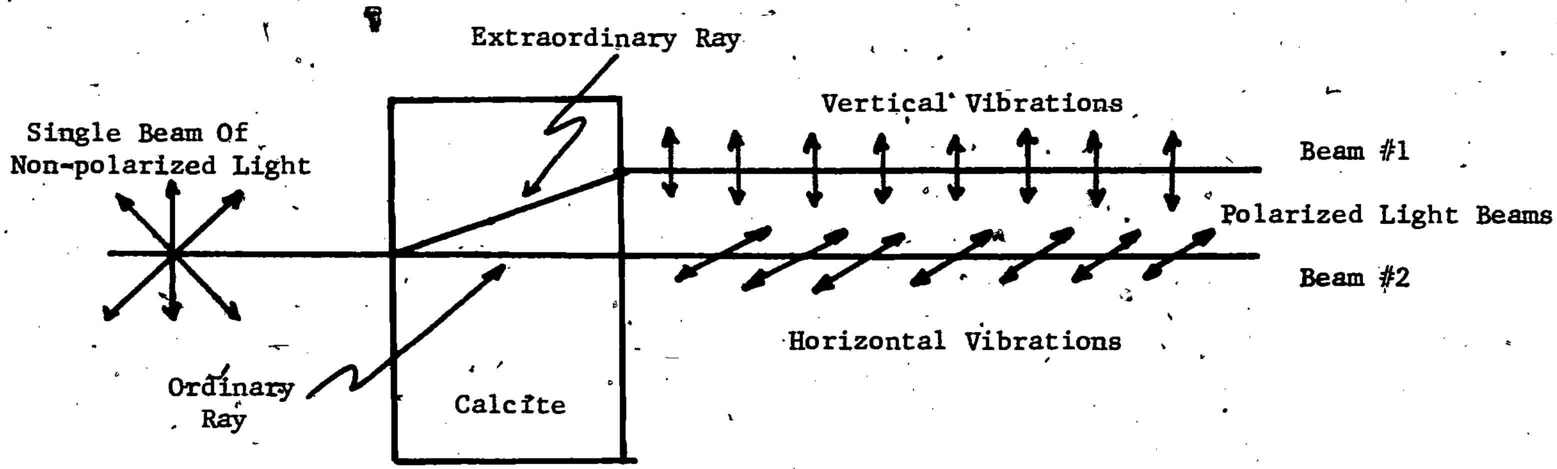
USING AN ANALYZER
Fig. 4

Polarization in certain crystals is based upon double refraction, a phenomenon exhibited by certain "doubly refracting" or "bi-refringent" crystals, such as calcite, quartz, or tourmaline. These

crystals exhibit two distinct optical axes and therefore possess two distinct indices of refraction, depending upon the direction of the light and the orientation of the electric field component passing through them. Thus, light passing through a crystal of Iceland spar (calcite) breaks up into two rays of equal intensity, one called the <u>ordinary ray</u> and the other called the <u>extraordinary ray</u> (see Figure 5, below). Because these two rays "see" different refractive indices, they each bend differently from their same (original) direction and are thus separated from each other upon emergence from the crystal.

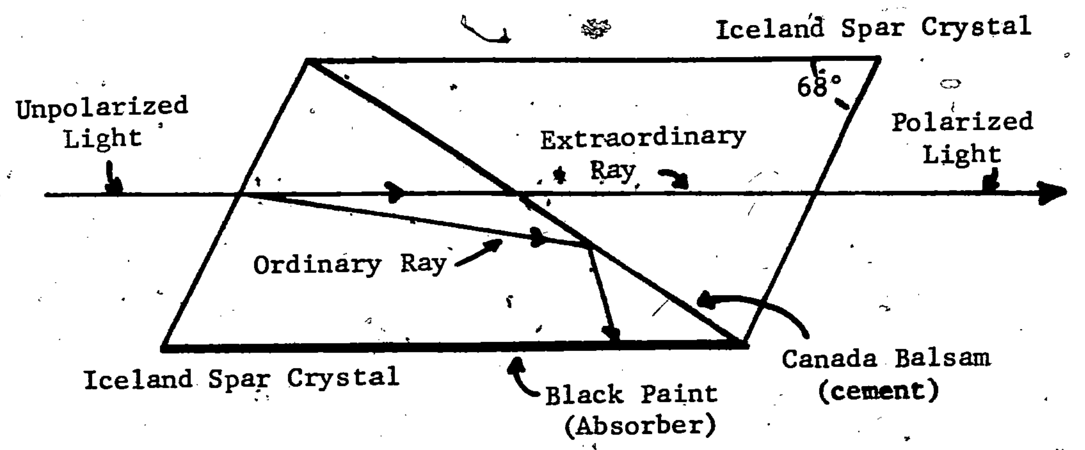


How print looks when viewed through doubly refracting crystal.



DOUBLE REFRACTION
Fig. 5

Each of the two beams of light are polarized, the ordinary beam consisting of horizontal vibrations; and the extraordinary beam, of vertical vibrations. Something different happens in a crystal of tourmaline. One of the polarized rays will be absorbed, and only one polarized ray will emerge; and in a nicol prism, two crystals are joined together to cause one polarized ray to be totally internally reflected (see Figure 6, below). The most convenient and least expensive polarizing material is a sheet of polaroid. This consists of an array of small polarizing crystals embedded in glass, or in a stretched plastic sheet, so as to polarize in a given direction. The tiny crystals increase the efficiency of the polarizer.

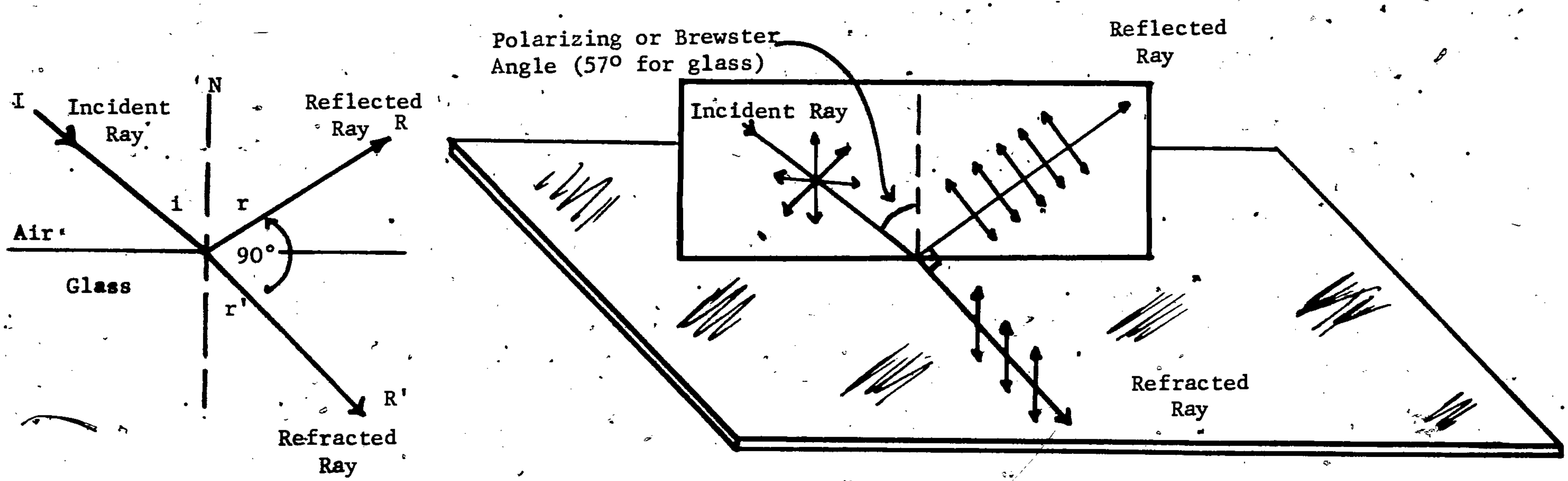


CROSS SECTION OF A NICOL PRISM
Fig. 6

Light may also be polarized by reflection. In the case of light falling obliquely at an angle on a sheet of glass, some of the light will be reflected and some will be transmitted. Both the reflected

light and the refracted light will be partially polarized (see Figure 7). If a special angle of incidence, the Brewster angle, is used, the reflected and refracted rays form a right angle with each other and the reflected light will be completely polarized (with the electric field component parallel to the reflecting surface). The refracted light is also polarized, but with its electric component perpendicular to the surface. The Brewster angle can be found by using the formula,

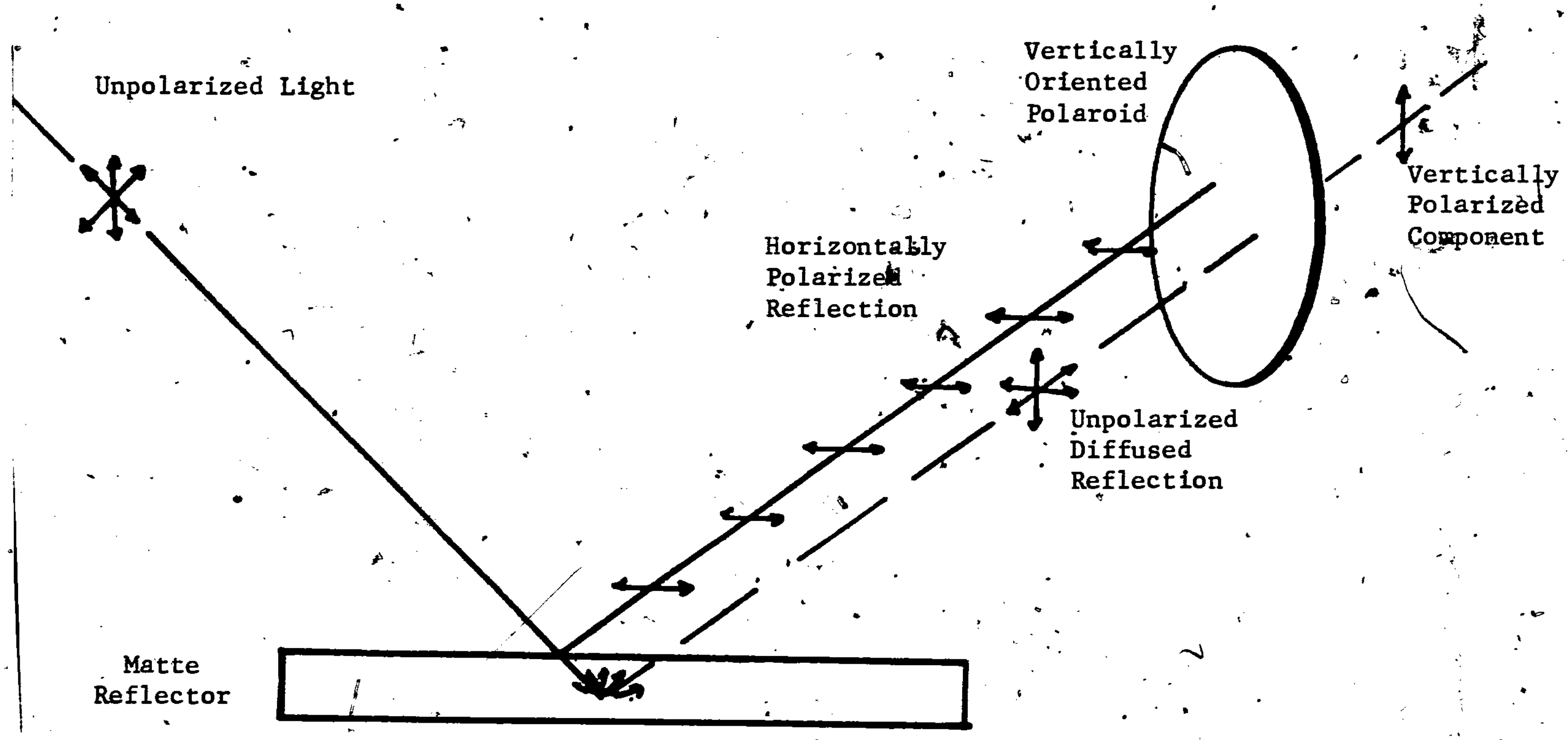
tan i = n, where n is the index of refraction.



POLARIZATION BY REFLECTION AND REFRACTION
Fig. 7

One important application of polarized light is the detection of strains in transparent materials. Glass, celluloid, or Bakelite do not extraordinarily affect polarized light passing through them. However, when subjected to stress, they become doubly refracting. If a stressed, transparent material (such as clear plastic) is placed between two crossed polaroids, the light passing through the first polaroid will leave its field planes rotated as it passes through the stressed material, with different colors rotated through different angles (by different amounts). The light will consequently emerge through the second polaroid with certain colors removed. The resulting stress patterns serve as the basis for <u>photoelastic analysis</u> in the study of engineering structures.

Sunglasses containing polarizing lenses may be used to control glare from water surfaces, road surfaces, and other non-metallic reflectors. The light reflected from non-metallic surfaces is partially polarized parallel to the reflecting surface (horizontally polarized). The horizontally polarized portion is easily reduced in intensity by the placement of vertically-oriented polaroid sunglasses. The unpolarized diffused (scattered) light passes through to the eye, being slightly modified by the sunglasses. Therefore, the useful part of the reflected light is retained (vision) and the objectionable part reduced (glass).



POLARIZATION BY REFLECTION
Fig. 8

RESOURCE PACKAGE 7-1.2

POLARIZED LIGHT II

You will need:

-- Crystal of calcite

-- Pan of polaroid film squares

-- Polaroid filters (discs)

-- Sheet of glass

-- Illuminator with stand and support

-- Cardboard screen with 3-cm diameter hole covered with a piece of tracing paper

-- Sheet of white cardboard

-- Large protractor

-- V-shaped Bakelite piece

-- Clear plastic comb

-- An improperly annealed glass test tube

-- U-shaped Bakelite member with a rivet hole near one corner

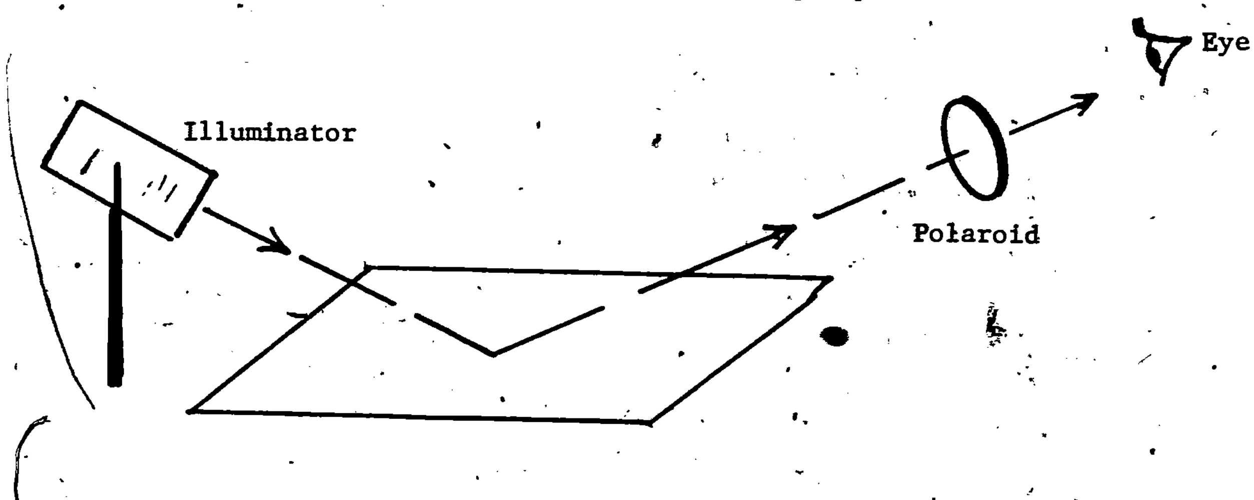
Arrange the illuminator and screen so that a diffused circular source of light is made available. Examine the light with each polaroid film. What structural change in the light waves is produced by each polaroid held separately in front of the light?

Place one filter over the other and examine the light passing through this combination (keep the polaroid filters next to the light source). Keep one filter in a fixed position and slowly rotate the other filter. Can you determine when transmission axes are parallel? Perpendicular?

Now place a clear crystal of calcite over the print on this page. Can you account for the appearance of the print? Examine what you see by rotating a single polaroid slowly in a plane parallel to that of the page. Record a description of this in your notebook.

Go to a window and view car windows, clouds, etc. while slowly rotating polarized materials such as discs, sunglasses, etc.

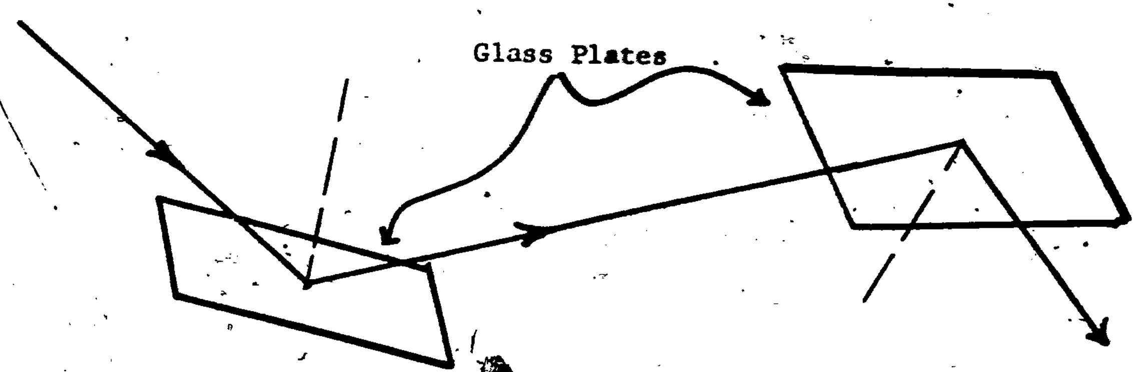
Place a strip of glass on a table and vary the angle of incidence of the light from the illuminator from about 40° to 70° (see diagram below). Look through a single polaroid filter at the image of the



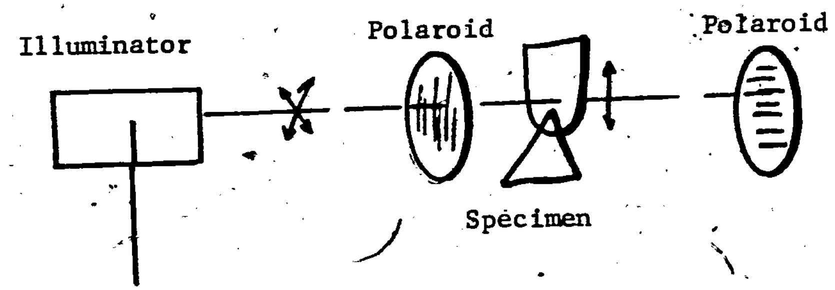
light source reflected from the glass. Rotate the filter so as to vary the brightness of the image from maximum to minimum. Does there appear to be a particular angle of incidence for which both the

transmission and extinction of light have a maximum value? Estimate and record this angle. Consult a trigonometric table of functions and determine the tangent of this angle. What important optical constant should be equal to this number?

Polarization can be obtained without the use of a polaroid filter by reflecting a beam at the proper angle from two glass plates. Mount a glass plate slanted at an angle of 33 degrees from the vertical. Shine a beam of light on the plate so that it is reflected straight down. Place a second plate under the first, mounted at the second angle. When the second plate is rotated about a vertical axis, the beam reflected from it can be made to disappear. This takes place when the light reflected from the second plate has a certain angle of incidence and reflection. What is this angle?



Arrange two polaroid filters in front of the illuminator so that the filters are in a light-extinguishing position. Insert between the filters first the V-shaped Bakelite piece, and then the U-shaped Bakelite piece (see diagram below). Record the effects observed, especially the changes in the pattern observed when the arms of the V- and U-specimens are gently pressed together. Record, also, the pattern around the rivet hole.



Repeat the experiment, using a clear plastic comb and an improperly annealed glass test tube. Squeeze the test tube gently and observe the change in patterns. Make a sketch of this pattern in your notebook.

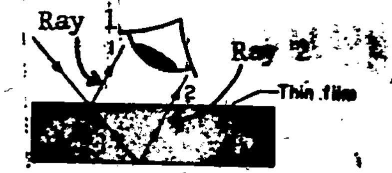
Place some crinkled cellophane (gum or cigarette package or wrappers), or some layers of cellophane, between the polarizers, and observe them.

RESOURCE PACKAGE 8-1.1

INTERFERENCE

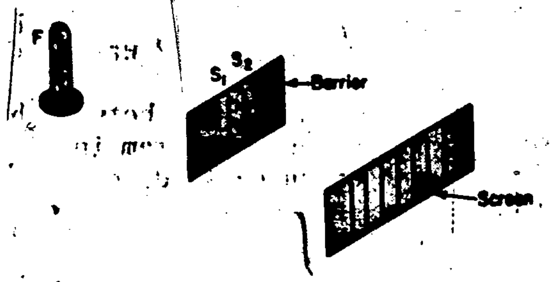
Interference occurs when two light waves pass through the same space at the same time; we say that the two waves are then superimposed. The two waves may reinforce each other (meet crest to crest, for example), giving constructive interference; or they may cancel each other (meet crest to trough, for example), giving destructive interference.

In order to observe interference, one needs two coherent sources, two sources that produce light with a constant relationship; i.e., the waves from each source are in step (crest together and trough together) and are in the same direction. Until recently, it has been impossible to get two independent light sources which were coherent. The reason for this is that most sources emit light in short bursts of unpredicted duration, of many different wavelengths, and in various directions. However, if we want interference of light, we can take light from one source, split it, and have it travel by two different paths to the same place, thus assuring coherency of "sources."



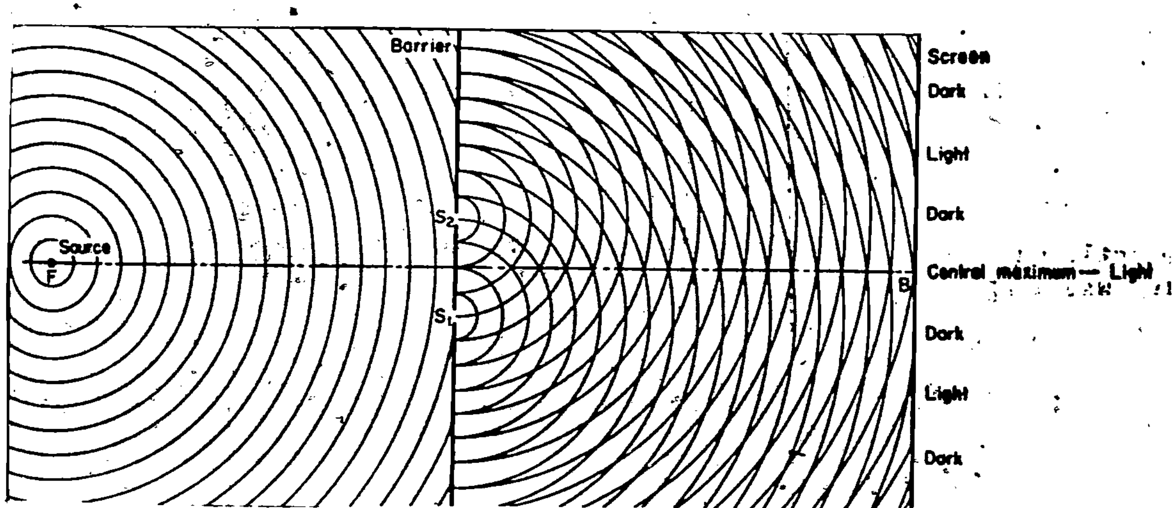
The colors observed on a soap bubble, and on thin films of oil, are due to interference of light. Let us assume that we have monochromatic light (light of just one color) incident on a thin film (the film may be oil, a soap solution, or even air trapped between two flat glass plates). Some of the light is reflected at the top of the film (ray 1 in the diagram);

most of the light goes through the film, and some is reflected at the bottom surface of the film and comes out again (ray 2 in the diagram). If you look down on the film, rays 1 and 2 will enter the eye and be focused on the retina. Thus, coherent light is coming to the eye from two different paths. Ray 2 had to go back and forth through the film. The two rays arriving at the retina will interfere with each other. Ray 2 may be delayed (phase changed) by some <u>whole number</u> of wavelengths (not <u>fractions of</u> wavelengths) by this process. If so, it will arrive at the eye in <u>phase</u> (in "step" with) ray 1, and the two rays will reinforce each other (as in a "crest to crest" meeting). An observer looking at a film from such a position will observe a bright spot; on the other hand, ray 2 may be delayed by some odd number of half wavelengths: $\frac{1}{2}\lambda$, $\frac{3}{2}\lambda$, $\frac{5}{2}\lambda$, etc. If so, it will arrive 180^{o} out of phase with ray 1, and the two rays will cancel each other. An observer looking at the film from such a position will see a dark spot. In general, such interference patterns consist of bright fringes alternating with dark fringes.



In 1801, Thomas Young performed a famous experiment which suggested the interference of light. Its essential features relate to the interference phenomena just described. Light from a small source <u>F</u> illuminates a barrier which has two small narrow slits, S_1 and S_2, very close together (see illustration at right). The light which gets through these two slits falls on a screen. Assuming that the light is monochromatic, we will see a series of bright lines alternating with dark regions. Assume that light spreads out from the source

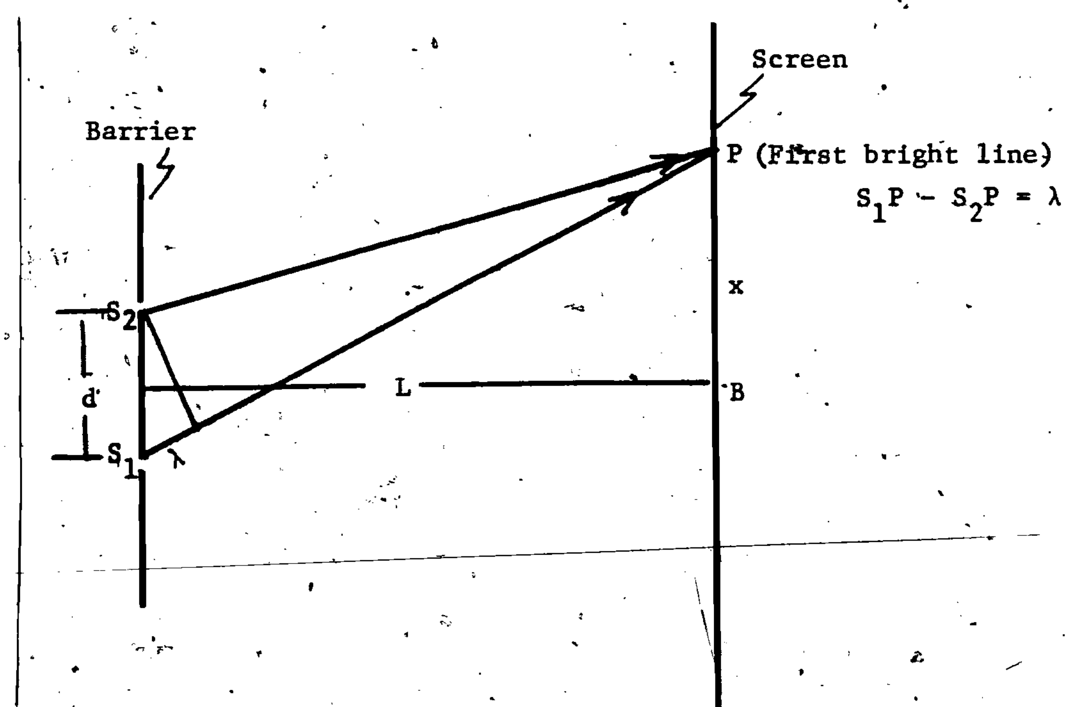
F in wave fronts. The two slits are equidistant from the source, and each wave front reaches S_1 and S_2 at the same time. Now, according to Huygens' Principle, we can think of a portion of the wave front at each slit acting like an independent source of light, and each slit then producing its own wave fronts. These are represented as two sets of circles with S_2 being the center at the top and S_1 the center at the bottom. Since the light originally came from a single source F, the waves produced by S_1 and S_2 are coherent. The waves overlap when they reach the screen and thus interfere with each other. In some places the waves arrive in phase and reinforce each other, giving a bright region or line. In other places, the waves arrive out of phase; a darker region will appear where the waves are out of phase. One such bright place is B (see Figure 1, below), which is equidistant from S_1 and S_2.



INTERFERENCE
Fig. 1

At this place there will be a central maximum, or a central bright line. There are other places, on either side of the central maximum, where bright lines appear; that is, places where the two wave fronts are in phase. At these locations, one wave is a whole number of wavelengths out of phase with the other (ahead or behind). The dark regions, between each light region, are produced where the waves are out of step by multiples of ½ of a wavelength (any odd number of half wavelengths).

To calculate the distance between bright lines, consider the diagram below. The first bright line on the upper side of the central maximum is represented by point P. It is bright because the wave from



S_2, traveling in direction S_2P, arrives in phase with the wave from S_1, which travels in the direction S_1P. The length of the path of S_1P is greater than S_2P. The waves can arrive in phase at the first bright line only if the lengths of the two paths are exactly one wavelength difference. For the second bright line, the difference in path is two wavelengths; for the third bright fringe, the difference is three wavelengths, etc.

If d is the distance between the slits, L, the distance between the barrier and the screen, and x, the distance between the central maximum and the first bright fringe, it can be shown that, for small values of x,

$$\frac{\lambda}{d} = \frac{x}{L}.$$

It can also be shown that the distance between the adjacent dark lines also has the same value of x. Complete cancellation occurs midway between the bright lines; the distance from one dark spot to the next is also x. Some of the important relationships are:

1) If the wavelength of light is increased by one wavelength (λ), the distance between the fringes increases.

2) If the distance between the slits (d) is decreased, the distance between the bright fringes increases.

3) If white light is used, the central maximum (at B) is white, and on either side of the central maximum bright fringes consisting of all the colors of the spectrum will appear. Violet will be the color closest to the central maximum.

4) If the distance between the screen and the slits (L) is increased, the distance between the bright fringes increases.

EXAMPLE: Calculate the distance between adjacent bright fringes if the light used has a wavelength of 6,000 Angstroms and the distance between the two slits is 2.0×10^{-3} meters. The distance between the screen and the slits is 0.5 meters.

$$\lambda = 6{,}000 \text{ Angstroms} = 6{,}000 \times 10^{-10} \text{ meters} = 6.0 \times 10^{-7} \text{ meters}$$

$$d = 2.0 \times 10^{-3} \text{ meters}$$

$$L = 0.5 \text{ meters}$$

$$x = ?$$

$$\frac{\lambda}{d} = \frac{x}{L} \qquad \frac{6.0 \times 10^{-7} \text{ meters}}{2.0 \times 10^{-3} \text{ meters}} = \frac{x}{0.5 \text{ meters}}$$

$$x = 1.5 \times 10^{-4} \text{ meters}$$

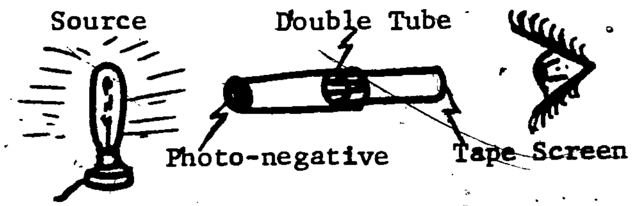
INVESTIGATING DOUBLE-SLIT INTERFERENCE

You will need:

--straight filament lamp
--photographic negative
--cardboard tubes
--Scotch tape
--translucent mending tape
--mercury, or other source lamp

To investigate the interference of a pattern of light, fasten a dark photographic negative (with two clear lines, or slits, across it) to one end of a cardboard tube. Make sure that the end of the tube is light-tight except for the two slits. (It helps to attach the film to the tube with black

tape.). Stick a piece of translucent ("frosted") tape over the end of a narrower tube that fits snugly inside the first one. Insert this narrow tube end into the wider tube (see Figure 2, at right). Set up the double tube at least 5 feet away from a straight filament lamp, with the slits held parallel to the filament.



DOUBLE SLIT INTERFERENCE
Fig. 2

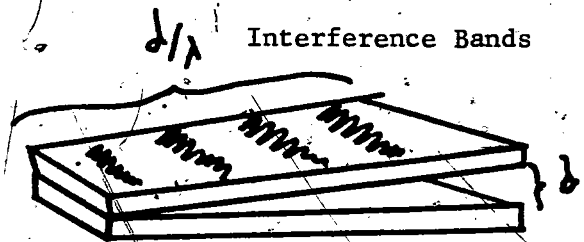
With your eyes about a foot away from the open end of the tube, focus your eyes on the tape screen. On the screen will be seen the interference patterns formed by the light from the two slits. What happens to the patterns as you move the screen farther from the slits? Try using another film with a different distance between the slits. Try putting different colored filters in front of the double slits. What are the differences between the patterns formed by blue light and those formed by red or yellow light? Record these answers in your notebook.

Take two clean microscope slides (or, better still, two optical flats) and press them together. Look at the light they reflect from a source (like a mercury lamp) that emits light at only a few definite wavelengths. What you will see is the result of interference between light waves reflected at the two inside surfaces which are almost, but not quite, touching; a thin film (a layer) of air is between the slides.

This interference phenomenon can be used to check the flatness of surfaces. If the two inside surfaces are flat planes, the interference fringes are parallel bands. Bumps or depressions (as small as a

fraction of a wavelength) can be detected as wiggles in the fringes. This method is used to measure very small distances in terms of a known wavelength of light of a particular color. If two very flat slides are placed at a slight angle to each other, an interference band appears for every wavelength of separation.

Interference Bands



How could this be used to measure the thickness of a very fine hair or very thin plastic? If your instructor has a PSSC physics lab manual, you can find detailed instructions for measuring such thicknesses. You may want to try it.

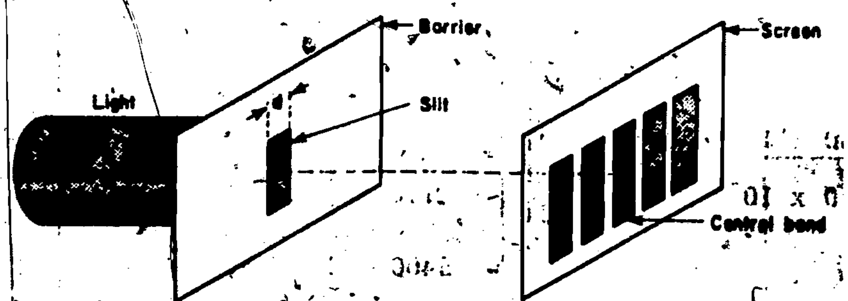
RESOURCE PACKAGE 8-1.2

DIFFRACTION

We know that waves bend around obstacles. An example of waves bending occurs when we hear a person speak, although our view may be blocked by a crowd of people or by a corner of a building. If we examine water waves, we can see waves going around a small object; and after a short distance, the waves look again as though there had been nothing in their way.

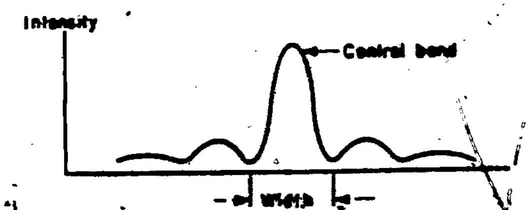
If light is a wave, why do objects cast sharp shadows? Why doesn't the light bend around the object and illuminate the region behind it? It can be shown that the smaller the wavelength, the smaller the diffraction (bending) effects. Since the wavelength of light is so small compared to most objects, light shadows are sharp, and light appears to travel in a straight line.

Of course, diffraction of light always occurs; but because light wavelength is so small, one must look very carefully to see this bending. Suppose you shine a beam of monochromatic light on an opaque barrier which has a narrow rectangular opening cut into it (a single narrow slit, as shown in Figure 1). Let the light which goes through the slit fall on a screen held parallel to the barrier. You



DIFFRACTION
Fig. 1

should expect that the part of the beam that gets through the barrier will have the same cross section as the slit, and that the illuminated part of the screen will look exactly like the slit in shape and size. If the slit is narrow, and one looks carefully, what actually will be seen on the screen are many rectangular parallel bands of light. Each band may be a little wider than the slit. The central band is very bright; but on each side of the central band, the bands decrease in brightness. The central band's intensity is about twenty times as great as the first bands on each side. In Figure 2, below, is a rough graph of the intensity of the observed pattern plotted against distance along the screen.



Intensity of Single Slit Diffraction Pattern

Fig. 2

In the diffraction pattern, the central band is also called the <u>central bright line</u>, or the <u>central maximum</u>. Analysis shows that

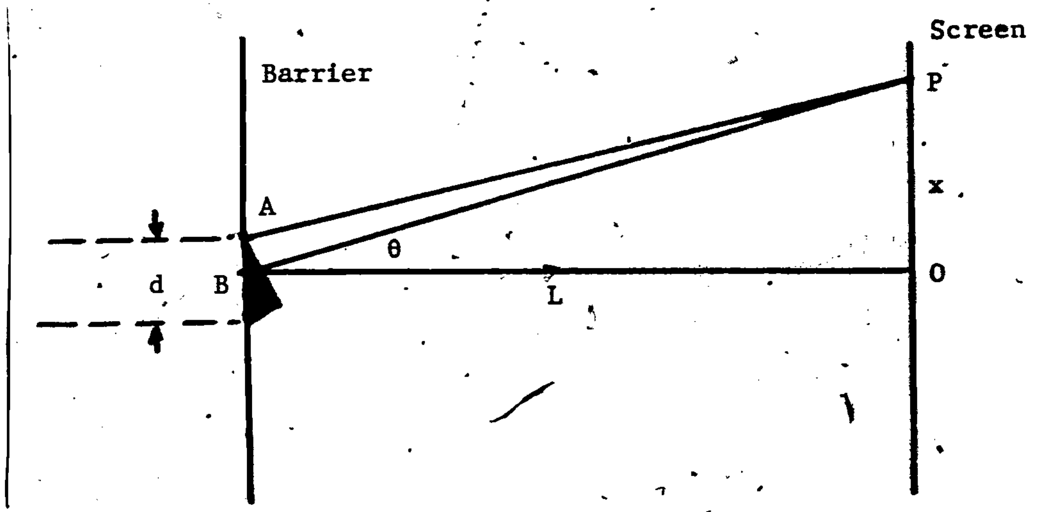
1) the width of the central maximum varies inversely as the width of the slit; that is, if the slit becomes narrower, the central maximum line becomes broader, or there is more bending of light around the edges of the slit.

2) the width of the central maximum varies directly with the wavelength. If the opening is large compared to the wavelength, the diffraction is negligible.

INVESTIGATING DIFFRACTION:

Use the space between two fingers, or the jaws of a vernier caliper, to form a narrow slit. Place these in front of a light source and see the interference bands.

As in the case of the double slit interference pattern, Huygens' Principle and the wave theory of light can be used to explain the single slit diffraction pattern. Look at Figure 3, below. Assume that the slit has a width <u>d</u> and that the barrier is a distance <u>L</u> from the screen. Consider a wave front arriving at the slit opening. According to Huygens' Principle, every point on the wave front can be thought of as sending out its own waves. Two such points are shown at <u>A</u> and <u>B</u> in the diagram.



SINGLE SLIT DIFFRACTION
Fig. 3

Think of the waves A and B going toward P, a point on the screen. If P is to be a dark spot on the screen, the two waves traveling along AP and BP must cancel each other. Notice that the light from the two points A and B travels different distances to the screen. Path BP is larger than path AP. If the difference in the path length is one-half wavelength, the two waves will cancel each other.

OPTIONAL:

It can be shown that for a dark point on the screen, $\sin\theta = \frac{n\lambda}{d}$, where d is the distance of the slit, λ is the wavelength of the light source, and $n = 1, 2, 3, \ldots$. When $n = 1$, P gives us the point of minimum intensity for the central line. Thus, the distance OP is half of the width of the central band. By looking at the relationship, $\sin\theta = \frac{\lambda}{d}$, it can be seen that as the wavelength increases, $\sin\theta$ increases; and, therefore, the width of the central band must increase. Also, if the width of the slit d decreases, $\sin\theta$ increases; and, therefore, the width of the central band must increase.

INVESTIGATING DIFFRACTION PATTERNS OF SLITS AND OF HOLES:

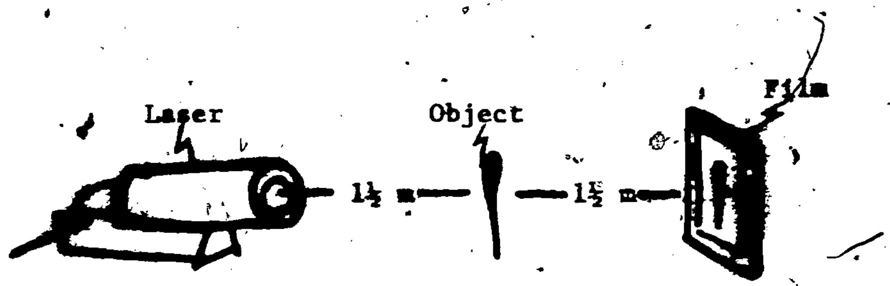
Examine laser light diffracted by a narrow slit. Then, try a circular hole instead of the slit. Sketch both diffraction patterns in your notebook.

INVESTIGATING DIFFRACTION BY OPAQUE OBJECTS:

Look at the diffraction of light by an obstacle. For example, use straight wires of different sizes (diameters) parallel to a laser light source. Also, use a circular object, such as a tiny sphere, the

head of a pin, etc. Also stretch a linen or cotton handkerchief of good quality and look through it at a distant light source, such as a street light about a block away. A piece of window screen will also work, in place of the handkerchief. Describe these observations in your notebook.

Diffraction patterns can be photographed. You must have a dark room or a large light-tight box. Expose a sheet of 3,000-ASA-speed Polaroid film for a few seconds. As a light source, use the laser. Razor blades, needles, or wire screens make good objects for photographing. Arrange the equipment as shown below.



RESOURCE PACKAGE 8-2.1

SELF-TEST

Work the following problems and answer the following questions on another sheet of paper.

1. Two parallel slits, 0.5 mm apart, are illuminated by light whose wavelength is 1.5×10^{-7} meters. A viewing screen is 2.0 meters away from the slits. What is the distance between two adjacent bright lines?

2. A double slit, with a spacing of 0.20 mm, is illuminated with light whose wavelength is 5,000 Angstrom units. An interference pattern appears on a screen 2.5 meters away. How far from the central bright image is the next bright line?

3. The continuous spectrum seen when looking at an oil film on street pavements is due to (1) pigment in the oil (2) prism effect for the different wavelengths (3) interference (4) diffraction.

4. In order to observe interference of light, the two light sources used must be (1) independent (2) coherent (3) dispersed (4) polarized.

5. Ann and John looked at the same white hot wire through a narrow slit. Ann's slit is narrower than John's. The distance between two adjacent red lines as seen by Ann as compared with that seen by John is (1) greater (2) the same (3) smaller.

6. The pattern when white light is seen through two adjacent slits is evidence that light (1) behaves like a wave (2) behaves like a stream of particles (3) can be polarized (4) is electromagnetic in nature.

7. Newton's rings are produced by (1) a pebble thrown obliquely into water (2) a lighted cigarette in pure oxygen (3) diffraction (4) interference.

8. Two light waves traveling by different paths reach a point on the screen in phase. One has an amplitude a; the other has amplitude b. The resulting amplitude is (1) (a + b) (2) (a - b) (3) $\frac{1}{2}$(a + b) (4) $\frac{1}{2}$(a - b).

9. An interference pattern has a black line. This results from two waves getting to the screen at the same time which are (1) in phase (2) one-half wavelength out of step (3) one wavelength out of step (4) two wavelengths out of step.

10. In the double slit experiment using monochromatic red light, if the distance between the slits is halved, the distance between two adjacent red lines in the interference patterns is (1) halved (2) doubled (3) quadrupled.

11. In the single slit diffraction pattern using monochromatic light (red), if the width of the slit is doubled, the width of the central maximum (1) decreases (2) increases (3) remains the same.

12. If the distance between the slits and the screen is doubled, the distance between the bright lines in the interference patterns is (1) halved (2) doubled (3) quadrupled (4) remains the same.

RESOURCE PACKAGE 8-2.2

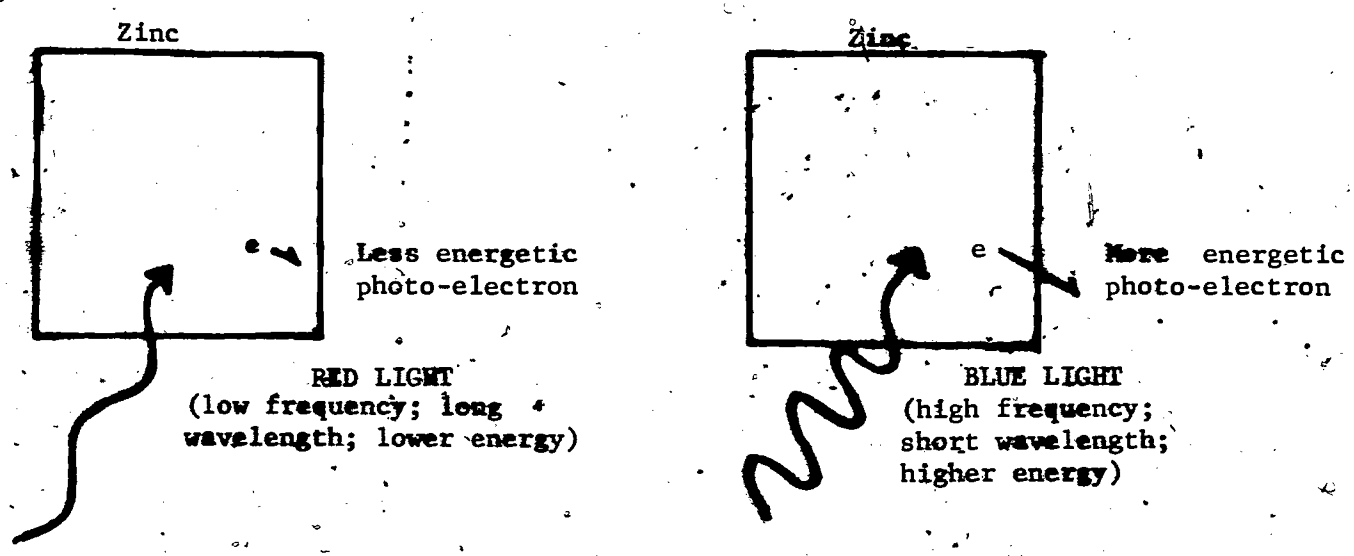
SELF-TEST ANSWERS

1. 6×10^{-4} meters
2. 6.25×10^{-3} meters
3. (3)
4. (2)
5. (1)
6. (1)
7. (4)
8. (1)
9. (2)
10. (2)
11. (2)
12. (2)

RESOURCE PACKAGE 9-1.1

PHOTOELECTRIC EFFECT

The emission of electrons from an illuminated metal is known as the photoelectric effect. It is found that a plate of freshly cleaned zinc acquires a positive charge; (i.e., becomes lacking in electrons) when exposed to light of relatively high frequency*, such as ultraviolet light. Further, the number of electrons emitted per second increases as the intensity of the light increases; also, the maximum energy of these electrons is directly proportional to the frequency of the incident light.



As illustrated in the figures above, the energy of the electron emitted from a zinc plate illuminated by lower-frequency (red) light is less than for higher-frequency (blue) light.

---

* High frequency implies high energy.

Many attempts were made to explain this effect; but it was Einstein, in 1905, who used the quantum or photon theory of radiation to explain what was happening. Einstein's equation for the photoelectric effect is:

$$\frac{1}{2}mv^2 = h\nu - \omega$$

where the terms on the left-hand side represent the maximum kinetic energy attained by an emitted electron and where the right-hand symbols are: h is Plank's constant (6.6 x 10^{-34} joule-sec); ν is the frequency of the incident light; and ω is the work function or the energy required to liberate the electrons from the surface of the illuminated material.

Strongly electropositive metals, such as lithium, sodium, potassium, or cesium emit an easily measurable supply of electrons when exposed to ultraviolet light and respond, to a lesser extent, to visible light as well. The polished zinc plate discussed earlier responds only to ultraviolet light, and would become insensitive if the source of ultraviolet were blocked by a sheet of ordinary glass (which absorbs this ultraviolet light). Platinum, on the other hand, is comparatively insensitive to light.

It should be noted that if the incident light is below a certain frequency, no electrons can be emitted from any metal, regardless of the intensity of the light incident upon its surface. This frequency boundary is known as the <u>photoelectric threshold</u>, and it is different for different metals.

INVESTIGATION OF PHOTOELECTRIC EFFECT:

You will need the following:

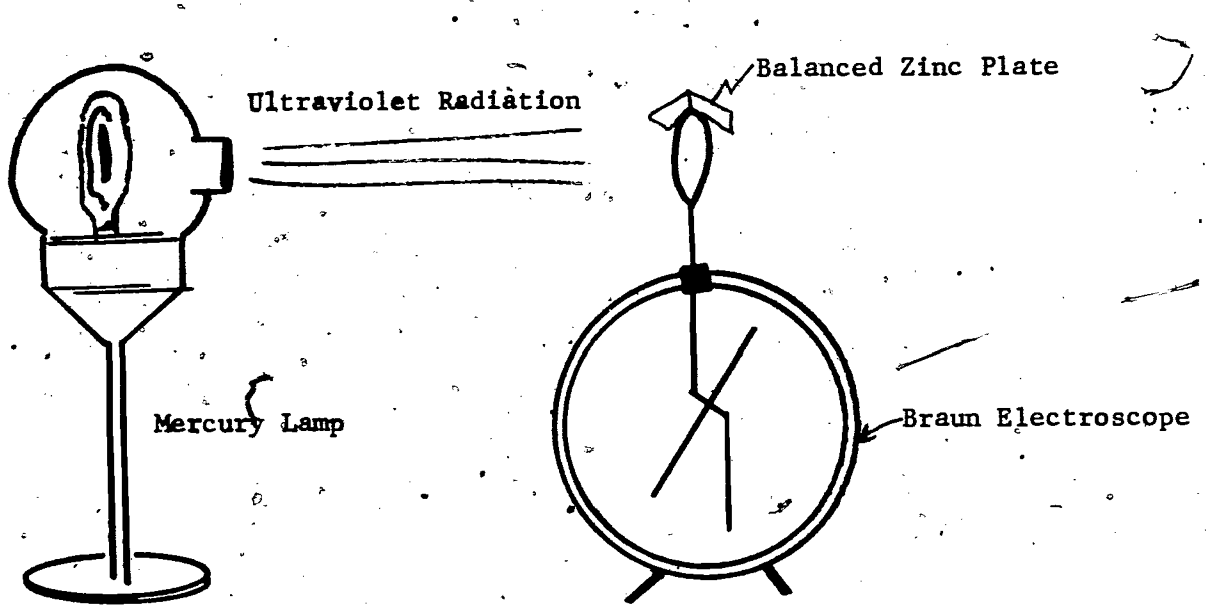
- high-pressure mercury arc lamp with quartz window and an associated power supply serving as a choke or inductive ballast for the lamp
- Braun electroscope with damp-proof insulation
- wooden blocks for height adjustment
- freshly sandpapered zinc plate
- sheet of polished aluminum
- square of plexiglass
- sheet of ordinary glass
- glass rod and crinkly wrapping tissue (+ electrification)
- polystyrene rod and wool (- electrification)
- stop watch (1/5 sec)
- sandpaper
- protective goggles

BE SURE TO SHIELD YOUR EYES FROM DIRECT EXPOSURE TO ULTRAVIOLET.

(ULTRAVIOLET LIGHT CAN CAUSE BLINDNESS EVEN THOUGH IT IS INVISIBLE.)

Cut and bend small corners in the zinc plate so that it may be balanced vertically on the knob of a Braun electroscope (see Figure 1 on page 150). Connect the mercury arc lamp, with the quartz window

temporarily directed away from the zinc plate. Remove all surface film (zinc oxide) from the plate by rubbing with sandpaper, and then place it in position on the electroscope. Charge the electroscope by directing the ultraviolet output directly upon the zinc plate. In your notebook, describe what happens to the leaves of the electroscope.



PHOTOELECTRIC EFFECT
Fig. 1

Discharge the electroscope and repeat the above, with the zinc plate charged <u>negatively</u>. (Your instructor can tell you how to do this.) Measure the time required for the full discharge of the electroscope.

Record this time. Now, discharge the electroscope and repeat the procedure, with the zinc plate charged positively. Try the same procedure with the aluminum plate, charging the electroscope first negatively and then positively. Record your observations and describe any differences in the effects that you observed between the two metals, the zinc and aluminum.

Again, charge the zinc plate negatively and repeat the procedure, but first place a sheet of plexiglass in the path of the ultraviolet beam. Next, repeat the procedure using a sheet of glass instead of plexiglass. Describe the results in your notebook.

By increasing the distance between the zinc plate and the mercury arc lamp, see if you can show that the number of electrons emitted per second is proportional to the intensity of the incident light. A factor of 2 increase in distance (doubling the distance) will result in a decrease in the intensity level by a factor of 4. What would you predict as to the number of electrons released per second at the different distances? To check your prediction, use a stop watch and record the time of complete discharge for different distances. Then make a graph in your notebook of time vs. distance.

QUESTIONS

In which industries is the photoelectric effect used? Which metals might be in greatest demand in these industries? What effect might the energy crisis have on further scientific studies of the photoelectric effect? Write a simple response to these in your notebook; your instructor can furnish suitable references for you.